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Operation and Maintenance Manual for Electrostatic Precipitators

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Manual

Operation and Maintenance Manual for Electrostatic Precipitators

Air and Energy Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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SECTION 1
INTRODUCTION

The success of an air pollution abatement program ultimately depends upon effective operation and maintenance (O&M) of the installed air pollution control equipment. Regardless of how well an air pollution control system is designed, poor O&M will lead to the deterioration of its various components and a resulting decrease in its particulate removal efficiency.

Effective O&M also affects equipment reliability, on-line availability, continuing regulatory compliance, and regulatory agency/source relations. Lack of timely and proper O&M leads to a gradual deterioration in the equipment, which in turn increases the probability of equipment failure and decreases both its reliability and on-line availability. These latter two items can decrease plant productivity if process operations are forced to be curtailed or shut down to minimize emissions during air pollution control equipment outages. Frequent violations of emission limits can result in more inspections, potential fines for noncompliance, and in some cases, mandatory shutdown until emission problems are solved.

This manual focuses on the operation and maintenance of typical electrostatic precipitators (ESP's). The overview presented in Section 2 summarizes the available information on theory and design in sufficient detail to provide a basic background for the O&M portions of the manual. Numerous documents are available if the reader desires a more rigorous treatment of ESP theory and design.

Although O&M-related air pollution problems cannot be completely eliminated, they can be minimized by the conscientious application of a well-planned O&M program. The causes of such problems often vary widely, and their effects on deteriorating performance may be direct, indirect, or synergistic.

Process, particle, mechanical, environmental, and gas-flow-dynamics factors dictate that O&M programs and trouble-shooting actions be approached from a total system or process/plantwide viewpoint. The variable nature of these factors also requires that O&M programs be individualized and specifically tailored to the needs of the process and installation served.

1.1 SCOPE AND CONTENT

Section 2 outlines the basic theory and principles of electrostatic precipitation in sufficient detail to provide the background for and understanding of the manual sections that follow. It describes common types of electrostatic precipitators (ESP's) and their components, notes typical ESP applications, discusses factors that affect performance, and lists the limits or constraints to ESP application. It also presents information on recent developments, research, and trends in the use and application of ESP equipment that are or may be useful in improving O&M. Discussions cover typical causes of poor ESP performance and how to prevent or minimize them; design, construction, and installation considerations that affect O&M; and the basic elements of an O&M program designed to attain and maintain optimal ESP performance.

Section 3 discusses performance monitoring as a major element in an O&M program. Initial discussion centers on the key parameters that define inlet/outlet gas stream conditions and ESP system operation. This discussion covers what is to be measured (or monitored), where the measurements should be taken, and the purpose of the measurements. Instrumentation systems are described and evaluated with respect to their use as performance monitors. Also discussed are the operating principle of monitors; their purpose; the use, advantages, and limitations of the output data. Performance tests, baseline assessments, and the role of parameter monitoring are briefly discussed, and the importance of good recordkeeping practices and procedures is stressed in regard to recordkeeping frequency, quality assurance, and records maintenance and retention.

Section 4 describes the use of performance monitoring and other data in the evaluation of control system performance, in the discovery of real or impending problems, and in the diagnosis and correction of causes of poor performance. Initial discussion centers on how the various data collected and recorded can be organized and used to track the performance of the overall control system and its components on both a short-term and long-term basis. Tracking procedures and trends analysis methods for assessment of current or impending performance deterioration are described. This section then focuses on the determination of probable causes of ESP operating problems, malfunction, and deteriorating performance. Recognition of the symptoms of deteriorating performance and problem diagnosis are covered. The actions generally required to restore the ESP to satisfactory operation are discussed. Detailed instructions are not given because specific corrective measures are highly system-dependent. Final discussion covers followup techniques for determining the success of corrective actions and verifying restored performance.

Section 5 presents guidelines for general O&M practices and procedures that can be used to improve and sustain control equipment performance and reliability. General guidance, rather than specific instructions, is given because of the unique nature of the various ESP control systems and the process streams they serve. This section prescribes the basic elements of good operating practice and preventive maintenance programs that can be used as the basis and framework for tailored, installation-specific programs. The section addresses proper startup/shutdown procedures and normal operating practices that prevent damage to equipment, minimize excessive emissions, and optimize service and performance. Schedules are suggested for inspection/observation of equipment items and for performing preventive maintenance on ESP systems and system components. These schedules indicate when and what to look for and why.

Section 6 presents methods and procedures for the detailed inspection of ESP systems and their components. Step-by-step procedures and techniques are provided for conducting external and internal inspections at both large and small ESP installations. Inspection during the pre-operational construction phase and the performance demonstration (baselining) period are addressed. The portable instrumentation and safety equipment needs during inspection are listed, and example inspection checklists are provided. Section 7 presents safety considerations and special precautionary measures for major source installations.

Section 8 summarizes the more important elements of an adequate O&M program by addressing the key items to be included in a model O&M plan. These areas include management and staff responsibilities, maintenance and operations manuals, spare parts, work order systems, computerized tracking, V-I curves, and procedures for handling malfunctions.

The appendices include a glossary of terms and industry specific sections on cement (Appendix A), kraft pulp mill recovery boilers (Appendix B), iron and steel industry (Appendix C), and municipal incineration (Appendix D). A set of example checklists for recording various O&M activities as well as example bid specification forms are presented in Appendix E.

1.2 INTENDED USE OF MANUAL

The increasing interest of both government and industry in proper O&M has created a need for informative O&M manuals to assist both source and control agency personnel. Obviously, no O&M manual for general application, guidance, and use can provide a solution to all the the many and varied O&M-related problems and combinations thereof. The objective of this manual is to present the elements of a sound and systematic maintenance, operation, surveillance, and diagnostic program that will promote the continuous, satisfactory performance of electrostatic precipitators at a high level of availability. The technical materials, procedures, techniques, and practices presented can be readily incorporated or adapted to fulfill the basic requirements of a site-specific O&M program.

The advice and suggestions of an advisory panel of governmental and industrial representatives were sought regarding the intended audience of the manual, its topical content, and the depth and level of detail to be devoted to each topic. Several panel members also provided technical data, general information, and operating experience that were useful in the preparation of the manual and critically reviewed draft sections as they were completed.

The manual is aimed at plant engineers, plant O&M personnel, and agency inspectors. Its intent is to serve as an educational tool, not an enforcement tool. Although the authors have focused on practical and proven O&M, they have also integrated relevant data from the literature, equipment manufacturers' files, operating and service manuals, field service reports, plant/equipment operating records, and case history experience. Emphasis is on operating practices; preventive maintenance procedures; performance monitoring; recordkeeping; and finding, diagnosing, and solving problems.

The plant engineer with responsibility for compliance with environmental requirements will find the following of particular interest:

- ESP design considerations to avoid O&M problems and facilitate maintenance
- Construction phase inspection to discover and/or prevent fabrication and installation errors
- Performance monitoring/evaluation and trends analyses to discover, diagnose, and correct real or impending problems
- Good O&M practices and key elements in an O&M plan
- Inspection methods and procedures

For plant operating and maintenance personnel, the topics of primary interest include:

- Operating practices and preventive maintenance
- Performance monitoring/record keeping/evaluation
- Malfunction and problem diagnosis/correction
- Inspection methods and procedures

For agency inspectors, the subjects of primary interest include those sections that address:

- Inspection methods and procedures
- Major elements of good O&M practice
- Common compliance-related problems encountered at major sources where ESP control systems are used
- Parameter monitoring/recordkeeping/evaluation of system performance
- ESP designs/installations that minimize O&M problems and provide safe, unhindered access for maintenance and inspection

The manual may also be used for a variety of secondary purposes. Colleges, universities, and technical schools that include air pollution courses in their curricula have a need for O&M information. The manual can also provide guidance on the general principles of O&M for new inspectors, plant engineers-in-training, and operators. Equipment manufacturers may find the manual useful as a guidance document regarding standard content and format in the preparation of equipment O&M manuals. Plant engineering personnel and consulting engineers will find the guidelines and principles set forth in the manual useful in their preparation of specifications and operating procedures.

SECTION 2

OVERVIEW OF ESP THEORY, DESIGN, AND O&M CONSIDERATIONS

This section provides an overview of ESP theory, design, and O&M considerations and sets the stage for more detailed treatment of O&M in later sections of this manual.

2.1 BASIC THEORY AND PRINCIPLES OF ELECTROSTATIC PRECIPITATION

2.1.1 Operating Principles

The basic principles of the electrostatic precipitation process are 1) development of a high-voltage direct current that is used to electrically charge (transfer to) particles in the gas stream (almost all commercial ESP's have negative polarity), 2) development of an electric field in the space between the discharge electrode and the positively charged collection electrode that propels the negatively charged ions and particulate matter toward the collection electrode, and 3) removal of the collected particulate by use of a rapping mechanism (or water flushing in the case of a wet collector). These basic principles of the electrostatic precipitation process are illustrated in Figure 2-1.

The electrostatic precipitation process occurs within an enclosed chamber; a high-voltage transformer (to step up the line voltage) and a rectifier (to convert AC voltage to DC) provide the power input. The precipitation chamber has a shell made of metal, tile, or Fiberglass Reinforced Plastic (FRP). Suspended within this shell are the grounded collecting electrodes (usually plates), which are connected to the grounded steel framework of the supporting structure and to an earth-driven ground. Suspended between the collection plates are the discharge electrodes (also known as corona electrodes, which are insulated from ground and negatively charged with voltages ranging from 20 kV to 100 kV. The large difference in voltage between the

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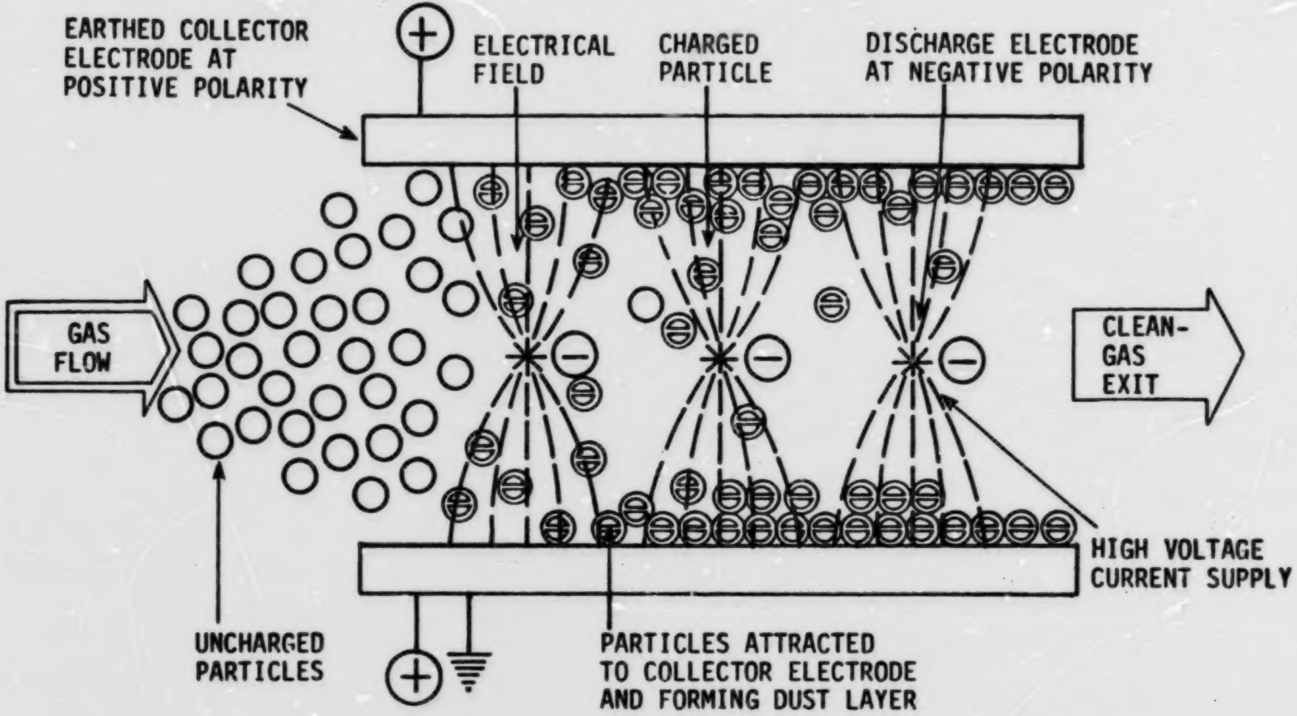
EARTHED COLLECTOR ELECTRODE AT POSITIVE POLARITY
+
ELECTRICAL FIELD
CHARGED PARTICLE
DISCHARGE ELECTRODE AT NEGATIVE POLARITY
GAS FLOW
CLEAN-GAS EXIT
HIGH VOLTAGE CURRENT SUPPLY
UNCHARGED PARTICLES
+
PARTICLES ATTRACTED TO COLLECTOR ELECTRODE AND FORMING DUST LAYER

Figure 2-1. Basic processes involved in electrostatic precipitation.

Source: Lodge Cottrell

negatively charged discharge electrode and positively charged collection electrode creates the electric field that drives the negatively charged ions and particles toward the collection electrode. The particles may travel some distance through the ESP before they are collected or they may be collected more than one time. Some particles lose their charge rapidly after being collected and are lost through reentrainment in the gas stream.

The last segment of the process covers the removal of the dust from the collection electrodes. In dry ESP's, this is accomplished by periodic striking of the collection and discharge electrode with a rapping device which can be activated by a solenoid, air pressure, or gravity after release of a magnetic field, or mechanically through a series of rotating cams, hammers, or vibrators. The particulate is collected in hoppers and then conveyed to storage or disposal.

In wet ESP's, the collected particulate is removed by an intermittent or continuous stream of water or other conducting fluid that flows down over the collection electrodes and into a receiving sump.

2.1.2 Gas Stream Factors Affecting Electrostatic Precipitation

Several important gas stream and particulate properties dictate how well an ESP will collect a given particulate matter. They include particle size distribution, flow rate, and resistivity which is influenced by the chemical composition, density of the particulate, and process temperature. These factors can also affect the corrosiveness of the dust and the ability to remove the dust from the plates and wires. Following are brief discussions of some of these properties.

Particle Size Distribution--

The coarser the size of a particle, the easier it is for an ESP to collect it. Particles in the 0.2- to 0.4-μm diameter range are the most difficult to collect because in this size range, the fundamental field charging mechanism gives way to diffusion charging by thermal ions (random collisions) as a charging mechanism for very small particles.

A large percentage of small particles (<1 μm) in the gas stream can suppress the generation of the charging corona in the inlet field of an ESP, and thus reduce the number of particles collected. Source personnel should have

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a good idea of the expected particle size of the particulate before purchasing an ESP, and the particle size distribution should be determined for the full range of the operating conditions. Performance as a function of particle size can be predicted by use of a computer model, as discussed later in this section. Figure 2-2 presents a typical plot of particle size versus efficiency.

Resistivity--

This parameter is a measure of how easy or difficult it is for a given particle to conduct electricity. The higher the measured resistivity (the value being expressed in ohm-cm), the harder it is for the particle to transfer the charge. Resistivity is influenced by the chemical composition of the gas stream and particulate, the moisture content of the gas stream, and the temperature.

Resistivity must be kept within reasonable limits for the ESP to perform as designed. The preferred range is 10^8 to 10^{10} ohm-cm. Table 2-1 presents the effects of various levels of resistivity on ESP operating characteristics.

This discussion on resistivity applies to dry ESP's only; resistivity is not important to the operation of a wet ESP.

Temperature--

The effect of temperature on resistivity and (ultimately on ESP collection efficiency) can be significant in some processes. Figure 2-3 illustrates the variation in resistivity with temperature for several different industrial dusts. Figure 2-4 shows the effect of temperature on ESP efficiency in a cement preheat kiln application in which the gas stream is normally conditioned and the temperature is reduced by a water spray tower. This figure illustrates the effect of temperature that is allowed to rise. Although not all temperature effects are this dramatic, the source should be aware of how resistivity varies with temperature in their particular process application.

Gas Volume/Velocity--

An ESP will operate best when the gas volume keeps the velocity within a typical range of 3.5 to 5.5 ft/s. Designers usually calculate a hypothetical average value for gas velocity from the gas flow and the cross section of the precipitator, ignoring the localized variances within the precipitator. The

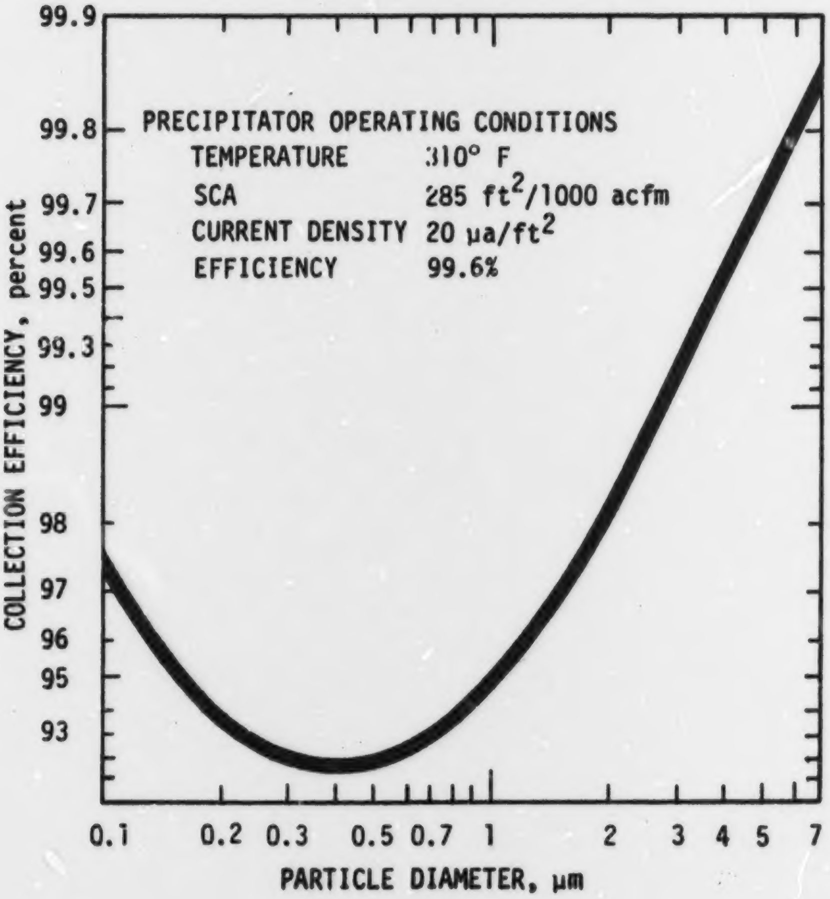

Figure 2-2. Typical curve showing efficiency as a function of particle size for an ESP collecting fly ash.[1]

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TABLE 2-1. ESP CHARACTERISTICS ASSOCIATED WITH DIFFERENT LEVELS OF RESISTIVITY[2]

Resistivity level, ohm-cm	ESP characteristics
Less than 10^8	(1) Normal operating voltage and current levels unless dust layer is thick enough to reduce plate clearances and cause higher current levels (2) Reduced electrical force component retaining collected dust, vulnerable to high reentrainment losses (3) Negligible voltage drop across dust layer (4) Reduced collection performance due to (2)
10^8 to 10^{10}	(1) Normal operating voltage and current levels (2) Negligible voltage drop across dust layer (3) Sufficient electrical force component retaining collected dust (4) High collection performance due to (1), (2), and (3)
10^{11}	(1) Reduced operating voltage and current levels with high spark rates (2) Significant voltage loss across dust layer (3) Moderate electrical force component retaining collected dust (4) Reduced collection performance due to (1) and (2)
Greater than 10^{12}	(1) Reduced operating voltage levels; high operating current levels if power supply controller is not operating properly (2) Very significant voltage loss across dust layer (3) High electrical force component retaining collected dust (4) Seriously reduced collection performance due to (1), (2), and probable back corona

Typical values

Operating voltage : 30 to 70 kV, dependent on design factors
Operating current density: 5 to 50 nA/cm^2
Dust layer thickness : ¼ to 1 in.

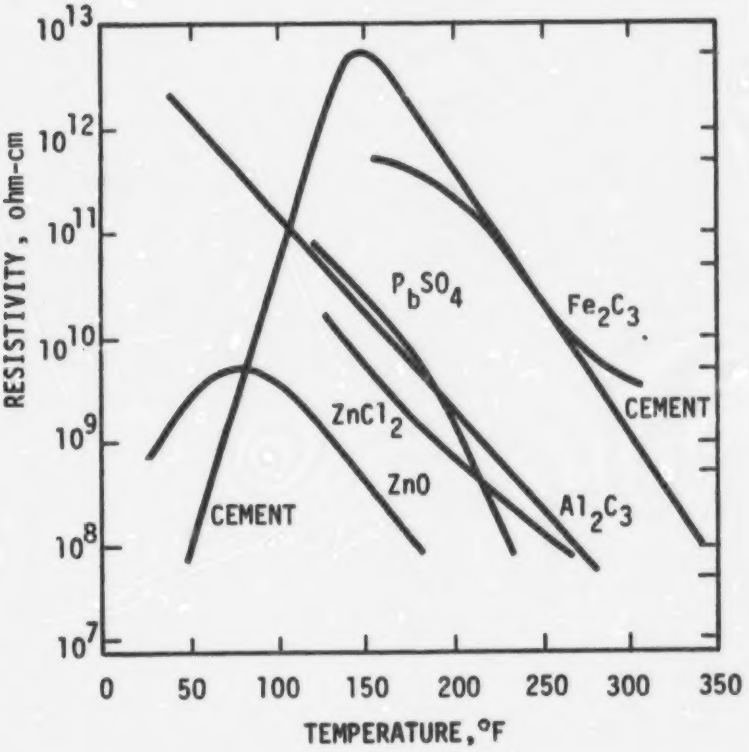

Figure 2-3. Resistivity of several dusts at various temperatures.[3]

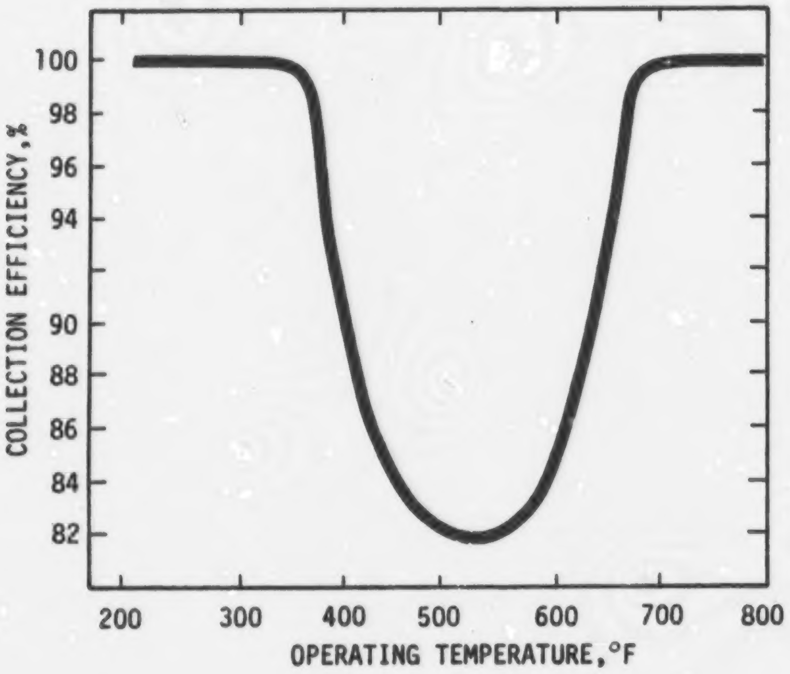

Figure 2-4. Effect of temperature on collection efficiency of an ESP in a cement preheat kiln application.[4]

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primary importance of the hypothetical gas velocity is to minimize potential losses through rapping and reentrainment. Above some critical velocity, these losses tend to increase rapidly because of the aerodynamic forces on the particles. This critical velocity is a function of gas flow, plate configuration, precipitator size, and other factors, such as resistivity. Figure 2-5 illustrates the effect of higher-than-optimum gas volume, using an outlet loading of 0.01 gr/acf is used as the base point. As shown, a gas volume of 10 percent over design increases the outlet loading by 50 percent, to 0.015 gr/acf.

Many ESP's are designed with some redundancy in treating the expected amount of flue gas. Nevertheless, the source should be aware of the design limits of the gas volume and take this information into account when considering process changes that will increase gas flow. Excessive air inleakage can also cause higher-than-expected gas volumes, but this problem can be remedied by proper design and maintenance of seals and expansion joints.

A final consideration is that of low gas volumes. If velocity is allowed to drop below 2 to 3 ft/s, performance problems can occur as a result of maldistribution of gas flow and dropout of dust in the ducts leading to the ESP. Building sufficient flexibility into the design of the ESP (e.g., a dampering system that allows a portion of the ESP to be closed off during periods of low gas flow) can minimize the problem.

Fuel-Related Parameters--

A decrease in the sulfur content of coal will generally result in an increase in resistivity and a reduction in the collection efficiency of the ESP. A switch from 2 percent Eastern bituminous coal to 0.5 percent Western subbituminous coal can cause an ESP designed for 99.5 percent collection efficiency to operate at 90 percent or less. Adequate amounts of certain chemical constituents of the particulate (e.g., sodium and iron oxide) can reduce resistivity and improve performance. Thus, is imperative that the source obtain an analysis of the ash or process dust and be prepared to design the ESP based on the worst fuel or process dust expected.

Because of its low resistivity, carbon is another constituent that can reduce ESP performance. The carbon particle is conductive, but it loses its charge quickly and becomes reentrained from the collection plates. This is

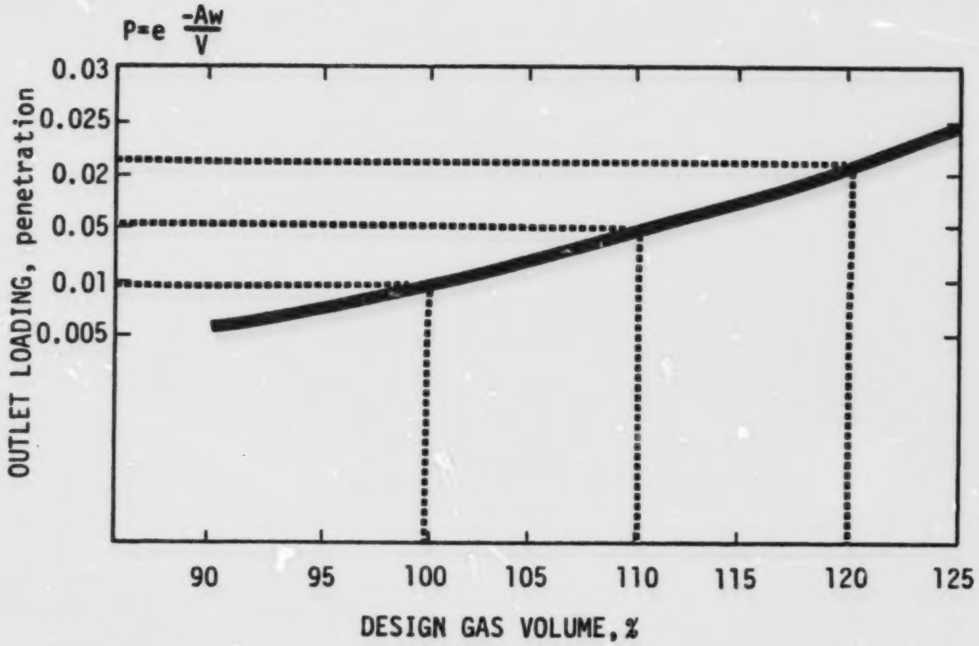

Figure 2-5. Effect of gas volume (reduced SCA) on outlet loading.[4]

aggravated by the fact that carbon is lighter than other constituents in the flue gas. This is a problem on coal-fired stoker boilers and coke oven underfire applications, for example, where the combustible content of the ash may range from 25 to 50 percent. The ESP's for these units are larger and have lower face velocity than those for applications where resistivity levels are normal.

2.1.3 ESP Design Equations and Models

Over the past 85+ years of applied ESP technology, a number of techniques have been used to estimate the amount of collection area required to produce the desired collection efficiency. All of these techniques, however, are based on the original Deutsch-Anderson equation,[5] which is as follows:

$$n = 1 - e^{-W\left(\frac{A}{V}\right)} \qquad \text{(Eq. 1)}$$

where n = ESP collection efficiency
A = Total collection electrode surface area
V = Gas flow rate
W = Migration velocity of the particles
e = Base of natural logarithms

The main problem with the Deutsch-Anderson equation (and the reason so many attempts have been made to modify it) is that it does not take into account the fact that 1) industrial process particulate matter is not monodisperse, and 2) the particle size distribution of dust suspended in the gas stream (and thus the migration velocity, i.e., how quickly the charged gas particles move to the grounded collection electrode) changes as the gas stream moves through the ESP. Also the equation does not account for other nonideal occurrences (such as gas turbulence and particle reentrainment) and assumes uniform electrical conditions throughout the ESP. When w is determined empirically, of course, these nonideal factors are accounted for.

The most well-known and frequently used variation on the Deutsch-Anderson equation is the Matts-Öhnfeldt version,[6] which is derived as:

$$n = 1 - e^{-(Aw_k/v)^k} \qquad \text{(Eq. 2)}$$

where n = ESP collection efficiency
A = Total collection electrode surface area
v = Gas flow rate
w_k = Modified migration velocity of particles
k = Dimensionless parameter
e = Base of natural logarithms

The value of the exponent k depends on the process being evaluated (most commonly 0.5 for typical fly ash applications). When $k = 1$, the Matts-Öhnfeldt again becomes the Deutsch-Anderson equation. The w_k value in the Matts-Öhnfeldt equation can be assumed to be independent of charging voltage and current levels and of particle size distribution within an ESP as the gas stream moves through it. If other gas stream changes occur, however, such as chemical composition, resistivity, or particle size distribution, w_k will be affected just as the conventional w is affected. Section 3 presents a discussion of a modified form of these relatively simple equations that a source operator will find very useful in estimating the current performance of an ESP in comparison with a baseline estimate by using the same equation in conjunction with a stack test.

Although the above equations form the basis of most sizing techniques, the total sizing procedure is much more involved. Each manufacturer has its own method of sizing, often involving the use of computer models, and always involving the use of some judgment because no model is capable of accounting for all of the variables that affect ESP performance.

Buyer participation also varies. Whereas some buyers rely heavily on the ESP manufacturer for determining proper sizing, in recent years other buyers have begun to take a more active role either directly or through use of their A/E. In fact, the A/E may make the final decision on what the minimum size of the ESP will be, as well as the types of components to be used.

EPA/Southern Research Model--

The best known and most widely used performance model for ESP's is one developed and refined by Southern Research Institute (SoRI) for the U.S. Environmental Protection Agency over the past 10 years.

The EPA/SoRI ESP model[7-10] is a valuable tool for examining and evaluating 1) gas/particulate characteristics, 2) design specifications, and 3) low or reduced process operating conditions that affect precipitator performance. Based on the inputs presented in Table 2-2, the model also can study typical problems and deficiencies of precipitator performance in light of actual performance results. The model is designed to accomplish the following:

- Predict collection efficiency as a function of particle size, electrical operating conditions, and gas/particulate properties.
- Calculate clean-plate, clean-air, and voltage-current characteristics.
- Determine particle charging levels by unipolar ions.
- Use empirical correction factors to adjust migration velocity results.
- Account for nonideal effects of gas distribution, gas bypass, and reentrainment from nonrapping sources.
- Account for rapping reentrainment.
- Predict trends caused by changes in specific collection area, voltage, current, particulate loading, and particle size.

Given accurate input data, the model usually can estimate emissions within ±20 percent of measured values. Such predictions are possible because a relationship can be established between secondary voltage and current levels (corona power) and emission levels through iterative computation by the model. Once the empirical factors are adjusted and agreement is reached, reasonable estimates of emission levels under other ESP conditions can be made. Although this model is obviously not simple, its complexity has been reduced sufficiently for it to be used with a programmable calculator.[11] The calculator version, although not always as accurate as the full-size model, is still a useful tool, especially for installations that do not have complex O&M problems.

Other Sizing Techniques--

The use of pilot-scale ESP's can help in sizing a full-scale unit and also for modeling flow patterns. The main problem with use of pilot-scale

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TABLE 2-2. INPUT DATA FOR EPA/SORI ESP COMPUTER MODEL

ESP specifications	Gas/particulate specifications
Estimated efficiency	Gas flow rate
Precipitator length	Gas pressure
Superficial gas velocity	Gas temperature
Fraction of sneakage/reentrainment	Gas viscosity
Normalized standard deviation of gas velocity distribution	Particulate concentration
Number of stages for sneakage/reentrainment	Particulate resistivity
Number of electrical sections in direction of gas flow	Particulate density
	Particle size distribution
For each electrical section	Dielectric constant
Length	Ion speed
Area	
Applied voltage	
Current	
Corona wire radius	
Corona wire length	
Wire-to-wire spacing (1/2)	
Wire-to-plate spacing	
Number of wires per linear section	

units is the scale-up factor because pilot-scale units usually perform better than full-scale units. This presents some uncertainty in the choice of proper scale-up factor.

Combustors are also useful for characterization of potential coal to be used in boilers. The installations available in the United States are small, and the data they provide are qualitative. Much additional information is needed for use with full-scale units.

2.1.4 ESP Applications

Dry ESP's are used in all basic industries and also in some specialized applications. The electric utility industry is the biggest user, but other large users include the cement industry (rotary kilns), the pulp and paper industry (kraft recovery boilers, coal, and hogged fuel boilers), municipal incinerators, ferrous metallurgical applications (BOF, sinter, scarfing), nonferrous metallurgical applications (copper, lead, zinc, and aluminum smelting), the petroleum industry (fluid catalytic crackers, detarring), the chemical industry (sulfuric acid plants), and industrial boilers of all types. The particulate matter from these sources can generally acquire an electrical charge quite well, and an ESP can be designed to treat large gas volumes at high temperatures (up to 2000°F) and several atmospheres of pressure.

Table 2-3 summarizes the percent of total capacity treated (1912 to 1969) and percent of total orders (1971 to 1980) for major areas of ESP application. These data show that ESP applications in the iron and steel and rock products industries have decreased in importance, whereas those in the pulp and paper and miscellaneous categories have increased in importance. Table 2-4 presents operating conditions of ESP's in major application areas. These data show the wide range of temperature, pressure, and particulate concentration under which an ESP can operate.

Problem Applications--

Wet ESP's are generally used for applications where the potential for explosion is high (closed-hood BOF in the steel industry), where particulates are very sticky, and for high-resistivity applications. Where moisture or

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TABLE 2-3. PERCENT OF TOTAL CAPACITY TREATED (1912-1969) OR FLANGE-TO-FLANGE ORDERS (1971-1980) FOR VARIOUS ESP APPLICATIONS (UNITED STATES AND CANADA)[12]

Application	1912-1969	1965-1969	1971-1975	1976-1980
Utility industry	78.6	88.9	77.3	80.3
Pulp and paper industry	5.1	4.5	6.7	7.2
Iron and steel industry	6.4	3.4	2.5	2.9
Rock products industry	6.4	2.1	2.6	3.2
Chemicals industry	1.0	0.4	-	-
Nonferrous metals	1.5	-	5.0	1.0
Petroleum industry	0.7	-	-	- (1980 0.4)
Miscellaneous	0.3	0.7	5.8	5.4

TABLE 2-4. OPERATING CONDITIONS OF ELECTROSTATIC PRECIPITATORS[12]

Application area	Temperature, °F	Pressure, psia	Concentration, gr/scf	Efficiency, %
Electric utility	225 - 900	14.7	1.5 - 7.5	90 - 99.6
Pulp and paper	225 - 375	14.7	1.0 - 9.0	90 - 99.5
Iron and steel	70 - 600	14.7	0.01 - 3.0	85 - 99.8
Rock products	350 - 700	14.7	3.7 - 156	92 - 99.9
Chemical process	80 - 800	14.7	0.2 - 50	85 - 99.9
Nonferrous metals	70 - 1100	14.7	0.01 - 45	90 - 99.9
Petroleum	70 - 850	7.5 - 164	0.8 - 40	80 - 99.7
Refuse combustion	450 - 550	14.7	0.5 - 4.0	95 - 99.2
Miscellaneous	90 - 1700	65 - 825	10^{-5} - 3.0	95 - 99.5

chemical substances are needed to increase the conductivity of the particulate (mostly low-sulfur coal applications), dry ESP's can be equipped with a conditioning system.

Moisture not only reduces the resistivity of most dusts and fumes at temperatures below 250° to 300°F, but also greatly enhances the effect of chemical conditioning agents. Moisture conditioning is performed by steam injection, water sprays, or wetting the raw materials before they enter the ESP. The lower the gas stream temperature, the better the conditioning effect is. Figure 2-6 presents an example of this effect for cement kiln dust. Proper spray nozzle design, adequate chamber space, and proper temperature control are imperative; otherwise, too much water can be provided and the particulate matter will cake on the interior of the ESP.

Chemical conditioning agents that are in use or under study include sulfur trioxide, sulfuric acid, ammonia, ammonium sulfate, triethylamine, compounds of sodium, and compounds of transition metals. Although high-resistivity problems are most commonly treated using conditioning agents, low-resistivity problems are also treatable (e.g., ammonia has been utilized). The ppm of these compounds required to provide the desired result is highly dependent on the application. Table 2-5 lists the conditioning agents and their mechanisms of operation.

In the United States, sulfur trioxide (SO_3) and sulfuric acid are the most successful and widely used conditioning agents on coal-fired utility boilers. The primary mechanism is condensation or adsorption on ash. The handling of both of these highly corrosive and toxic liquids is different because they must be vaporized before they are injected into the flue gas. Figure 2-7 shows a typical SO_3 conditioning system.

Although flue gas conditioning often improves ESP performance by reducing dust resistivity or through other mechanisms, conditioning agents should not be considered cure-alls for ESP problems. For example, they cannot correct problems associated with a poorly designed ESP, poor gas distribution, misaligned plates and wires, or inadequate rapping. Thus, any existing installation should be carefully evaluated to determine that poor ESP performance is due entirely to resistivity problems. Conditions for injection

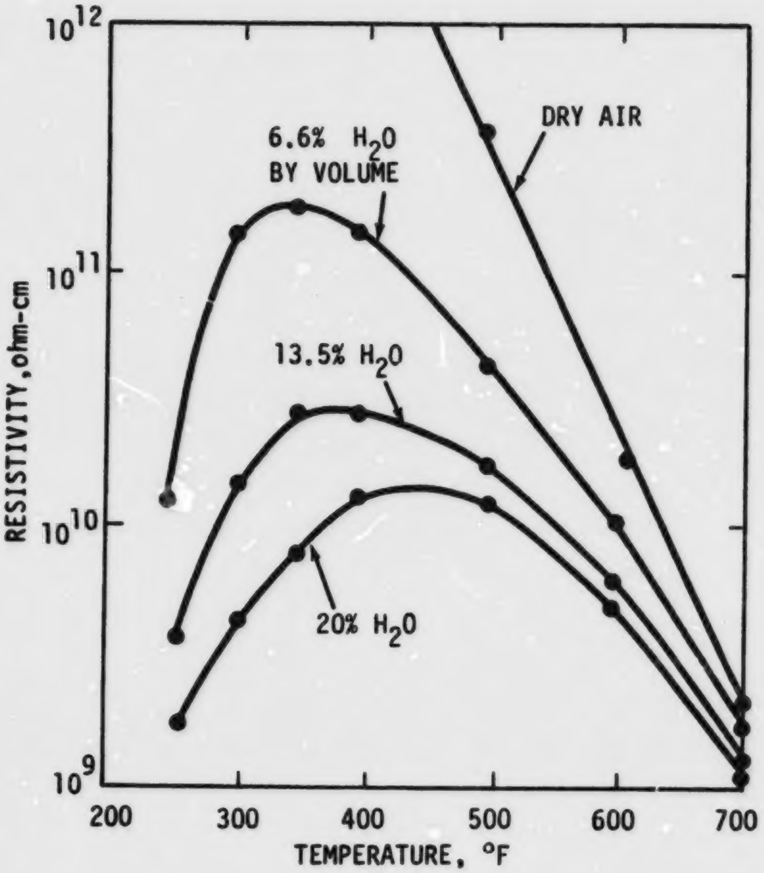

Figure 2-6. Moisture conditioning of cement kiln dust.[13]

TABLE 2-5. REACTION MECHANISMS OF MAJOR CONDITIONING AGENTS[14]

Conditioning agent	Mechanism(s) of action
Sulfur trioxide and sulfuric acid	Condensation and adsorption on fly ash surfaces; may also increase cohesiveness of fly ash. Reduces resistivity
Ammonia	Mechanism is not clear; various ones proposed: Modifies resistivity Increases ash cohesiveness Enhances space charge effect
Ammonium sulfate[a]	Little is known about the actual mechanism; claims are made for the following: Modifies resistivity (depends upon injection temperature) Increases ash cohesiveness Enhances space charge effect Experimental data lacking to substantiate which of these is predominant
Triethylamine	Particle agglomeration claimed; no supporting data
Sodium compounds	Natural conditioner if added with coal. Resistivity modifier if injected into gas stream
Compounds of transition metals	Postulated that they catalyze oxidation of SO_2 to SO_3; no definitive tests with fly ash to verify this postulation
Potassium sulfate and sodium chloride	In cement and lime kiln ESP's: Resistivity modifiers in the gas stream NaCl--natural conditioner when mixed with coal

[a] If injection occurs at a temperature greater than about 600°F, dissociation into ammonia and sulfur trioxide results. Depending upon the ash, SO_2 may preferentially interact with flyash as SO_3 conditioning. The remainder recombines with ammonia to add to the space charge as well as increase the cohesivity of the ash.

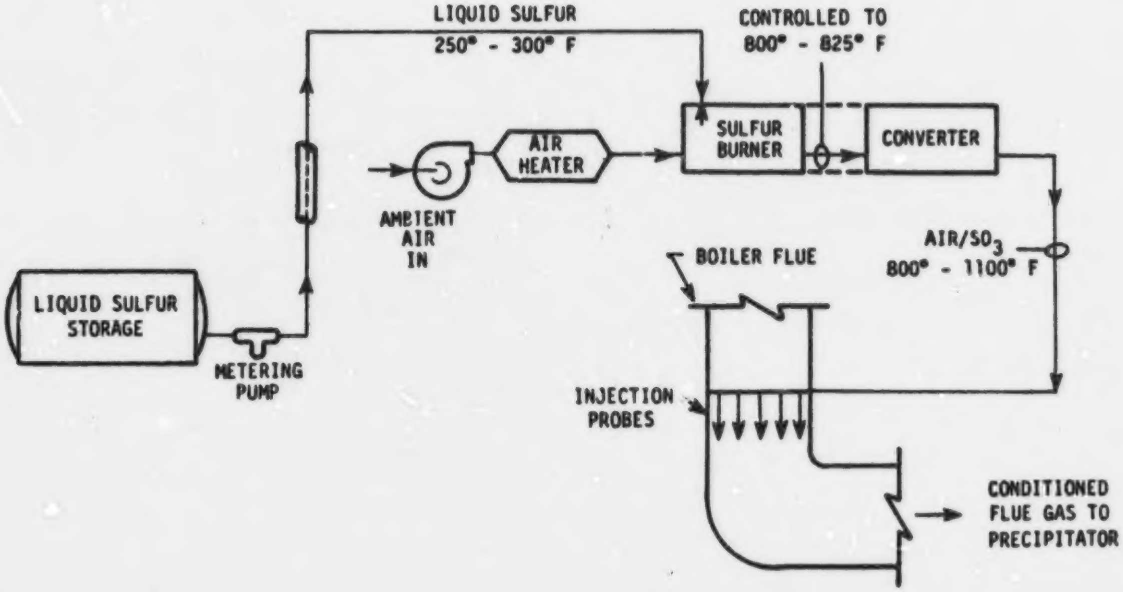

Figure 2-7. Flow diagram of sulfur-burning flue gas conditioning system. (Courtesy of Wahlco, Inc.)

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of a chemical conditioning agent should also be carefully studied. Inadequate mixing of the conditioner can cause performance to be below that expected.

The use of wet ESP's also can overcome resistivity problems. A wet ESP can be used alone or in conjunction with wet scrubbers, which remove both particulate and gaseous pollutants (such as fluorides). Wet ESP's are used to control a variety of industrial processes, including sulfuric acid mist; coke oven off-gas, blast furnaces, detarring, basic oxygen furnaces, scarfers, and cupolas in the iron and steel industry; and aluminum potlines. The conditioning of the incoming gas stream and continual washing of the internal components with water eliminate resistivity and reentrainment problems. Some gaseous pollutant removal can also occur, but such removal is limited by the solubility of the gaseous component of the wash liquor. Organics that condense are also collected in a wet ESP. Significant collection of submicron particles is also possible with a wet ESP.

2.2 ESP SYSTEMS AND COMPONENTS

This section discusses the major types of ESP's and describes their major components in terms of typical design features and construction procedures that are related to the operation and maintenance of the equipment over its useful life. New design and research and development are also discussed briefly.

2.2.1 Dry ESP's

The major distinction between different types of dry ESP's is the type of corona discharge system used. The three most common discharge electrode configurations used are 1) wires suspended or tensioned by weights (weighted wire), 2) wires suspended in a rigid frame, and 3) rigid electrode. The rigid electrode does not utilize wires but creates a corona on spikes welded or otherwise attached to a rigid mast support. Figures 2-8 through 2-10 show a typical wire-weight (American type) ESP, a rigid-frame (European type) ESP, and rigid electrode type ESP, respectively. Other differences in the design of wire-weight and rigid-type ESP's are discussed under the appropriate component (e.g., rapping equipment, etc.).

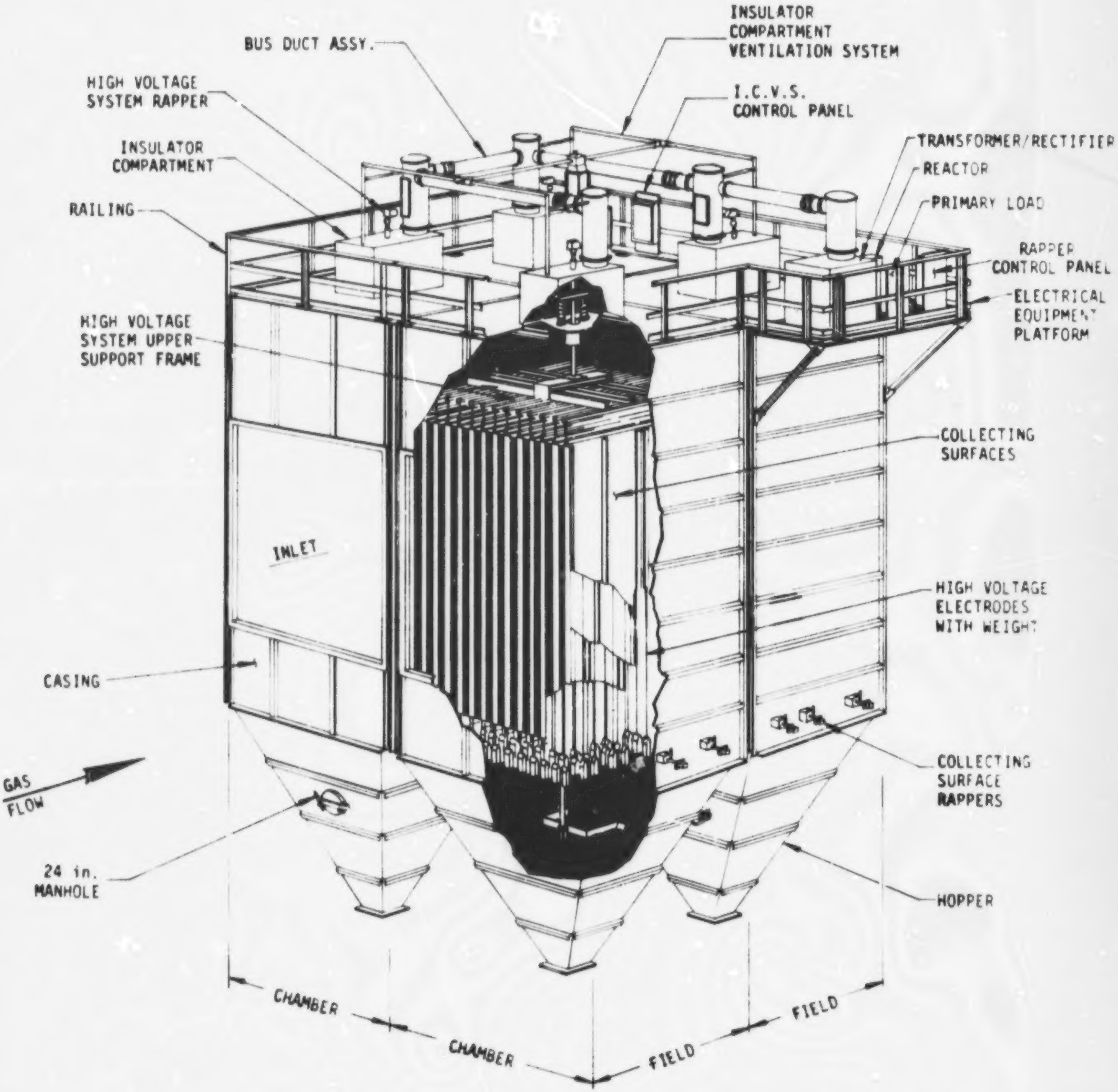

Figure 2-8. Typical wire-weight electrostatic precipitator with top housing.
(Courtesy of Western Precipitation)

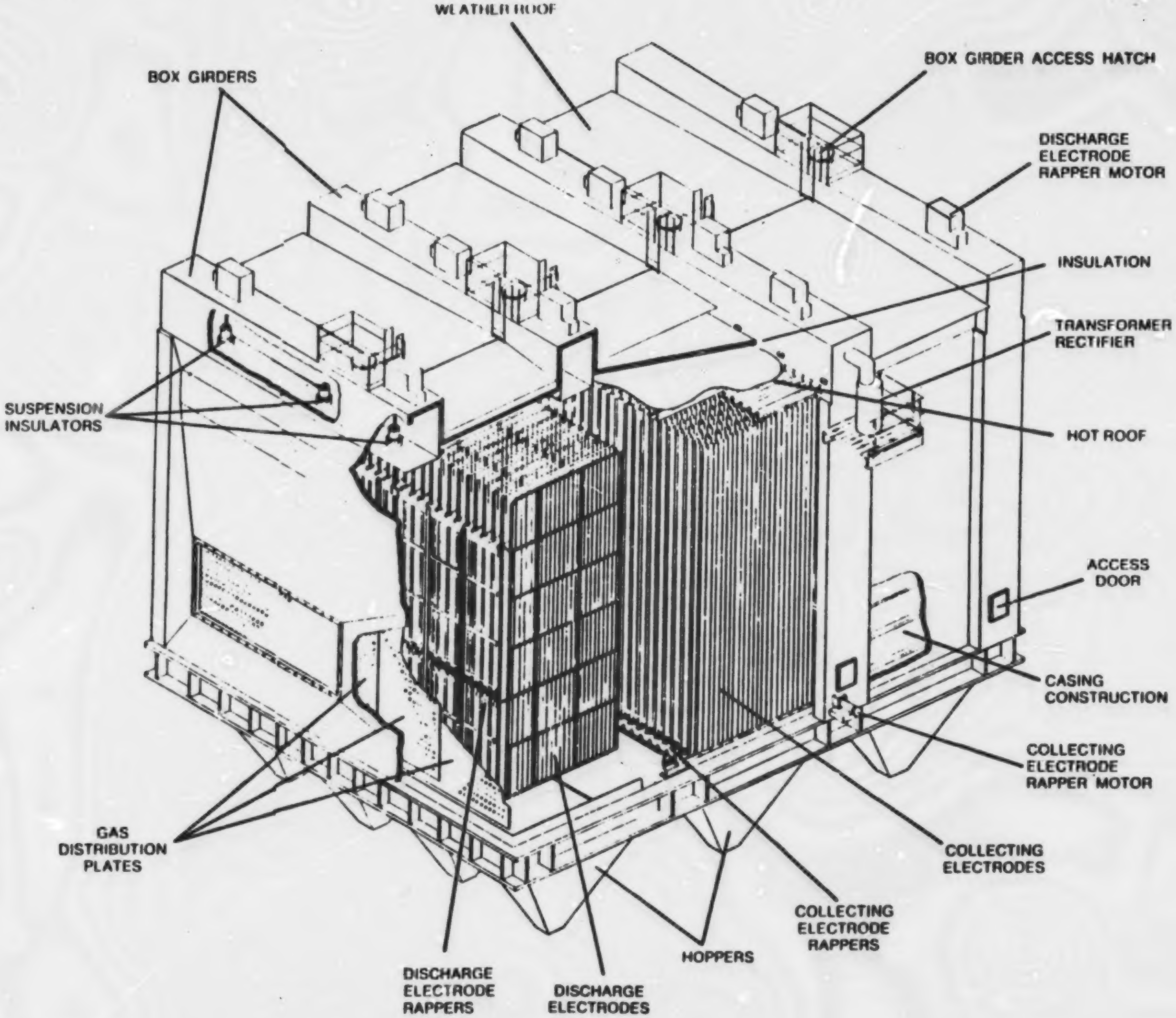

Figure 2-9. Typical rigid-frame (European type) ESP.
(Courtesy of Wheelabrator Frye)

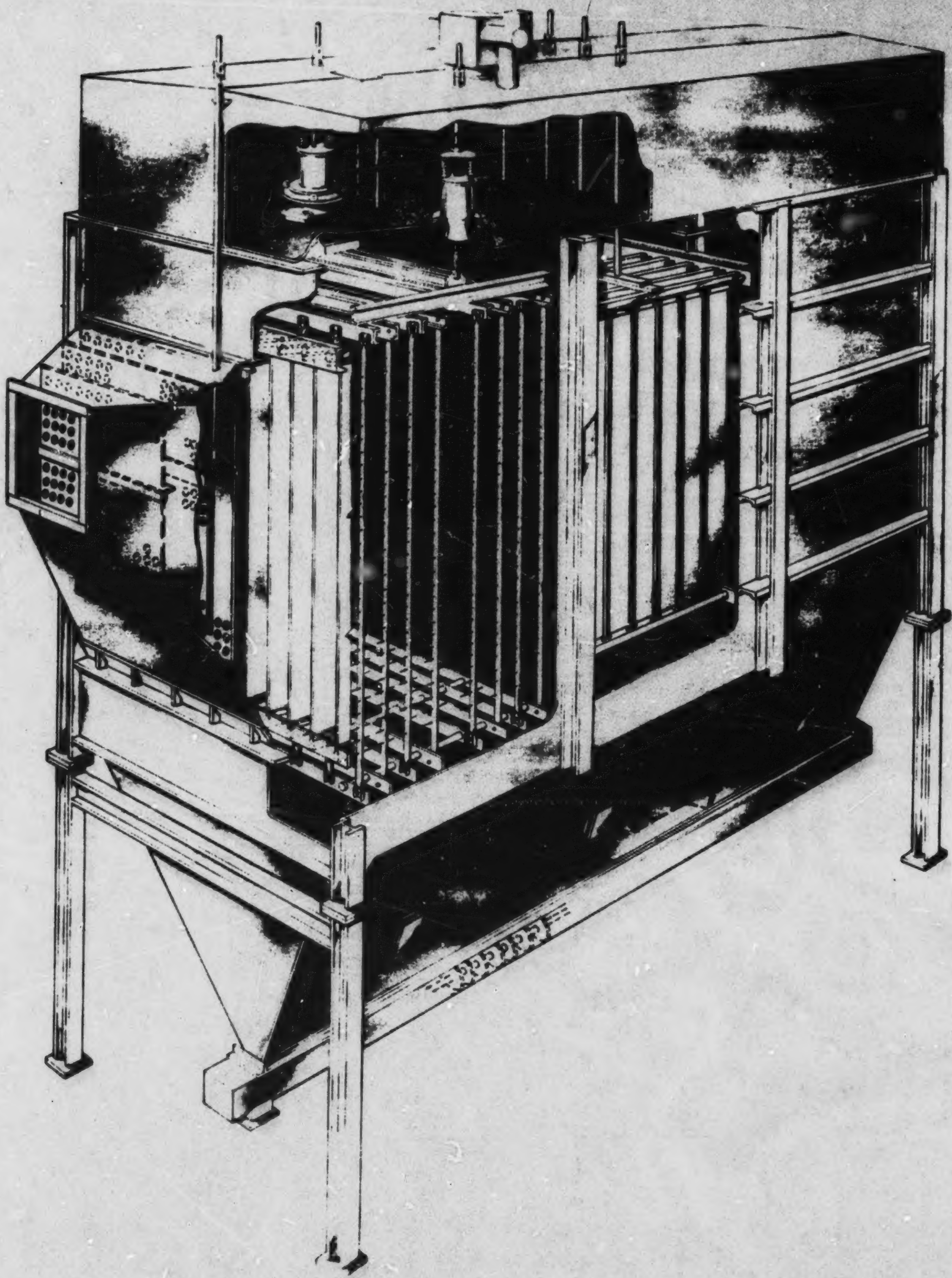

Figure 2-10. Typical rigid-electrode-type ESP (courtesy of Environmental Elements Inc.).

The wire-weight design was the typical American ESP from the late 1950's to the mid-1970's. Since then, users have shown an overall preference (heavily influenced by the utility industry) for rigid-type ESP's, because of their more conservative and higher cost design, the ability to provide longer discharge electrodes (generally greater than 36 ft) without an increase in breakage rate, and their ability to provide higher rapping force without damage to internal components (especially important in removing the highly resistive fly ash generated by low-sulfur coal). U.S. manufacturers are now offering ESP's of rigid-frame design and some of the so-called "hybrid" design in which a rigid-type electrode is combined with an American-type rapping system (e.g., magnetic impulse, gravity impact, pneumatic impact) instead of the European-type mechanical hammers. In 1980, more than 75 percent of all ESP orders in the United States were for rigid-frame ESP's.[12]

One other application of the wire-weight ESP (and to a very limited extent, the rigid-frame-type ESP), the hot-side ESP, is used primarily in the electric utility industry. This unit is placed upstream of the air preheater, where temperatures range from 600° to 700°F. Normally, the higher gas temperature dramatically reduces the resistivity of low-sulfur coal ash, which makes the installation of a hot-side ESP more economical than the larger size cold-side ESP that would be needed on the same type of installation. In the early to mid-1970's, approximately 100 hot-side units were installed on utility boilers firing low-sulfur coal. Results showed that units firing coal with low sodium content experienced high resistivity and reduced performance. It was found that sodium conditioning reduced resistivity and improved performance on units firing low-sodium coal; however, no hot-side ESP's have been sold in the United States since 1977.

Wet ESP's--

The major differences in the types of wet ESP's available today are as follows: the shape of the collector, whether treatment of the gas stream is vertical or horizontal, whether incoming gas is preconditioned with water sprays, and whether the entire ESP is operated wet. Figures 2-11 through 2-13 show three different types of wet ESP's, two of the circular-plate/pipe

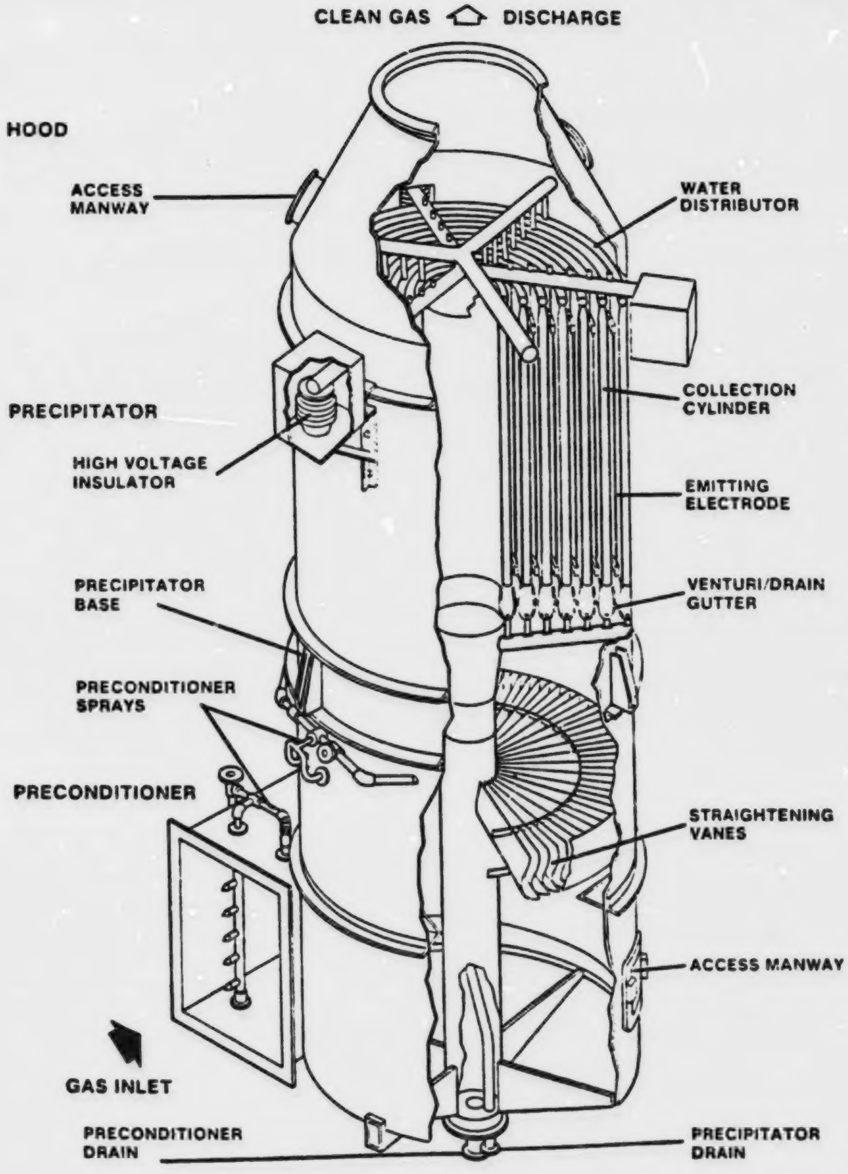

Figure 2-11. Concentric-plate wet ESP.
(Courtesy of Fluid Ionics, Inc.)

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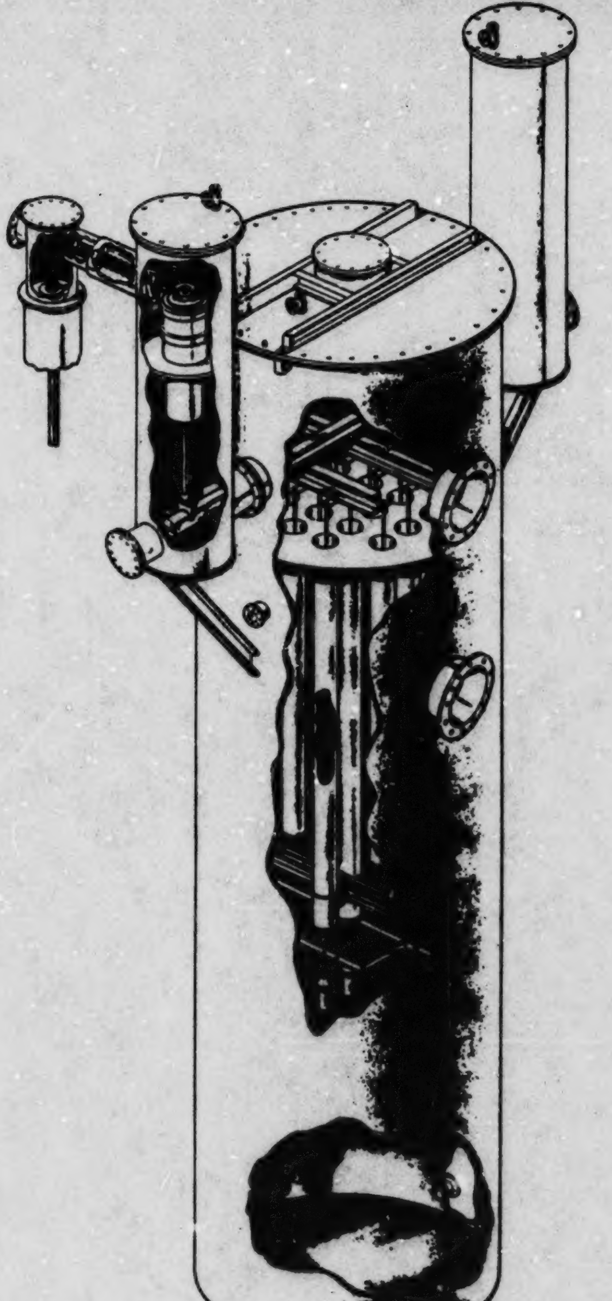

Figure 2-12. Circular-plate wet ESP (detarring operations). (Courtesy of Environmental Elements, Inc.)

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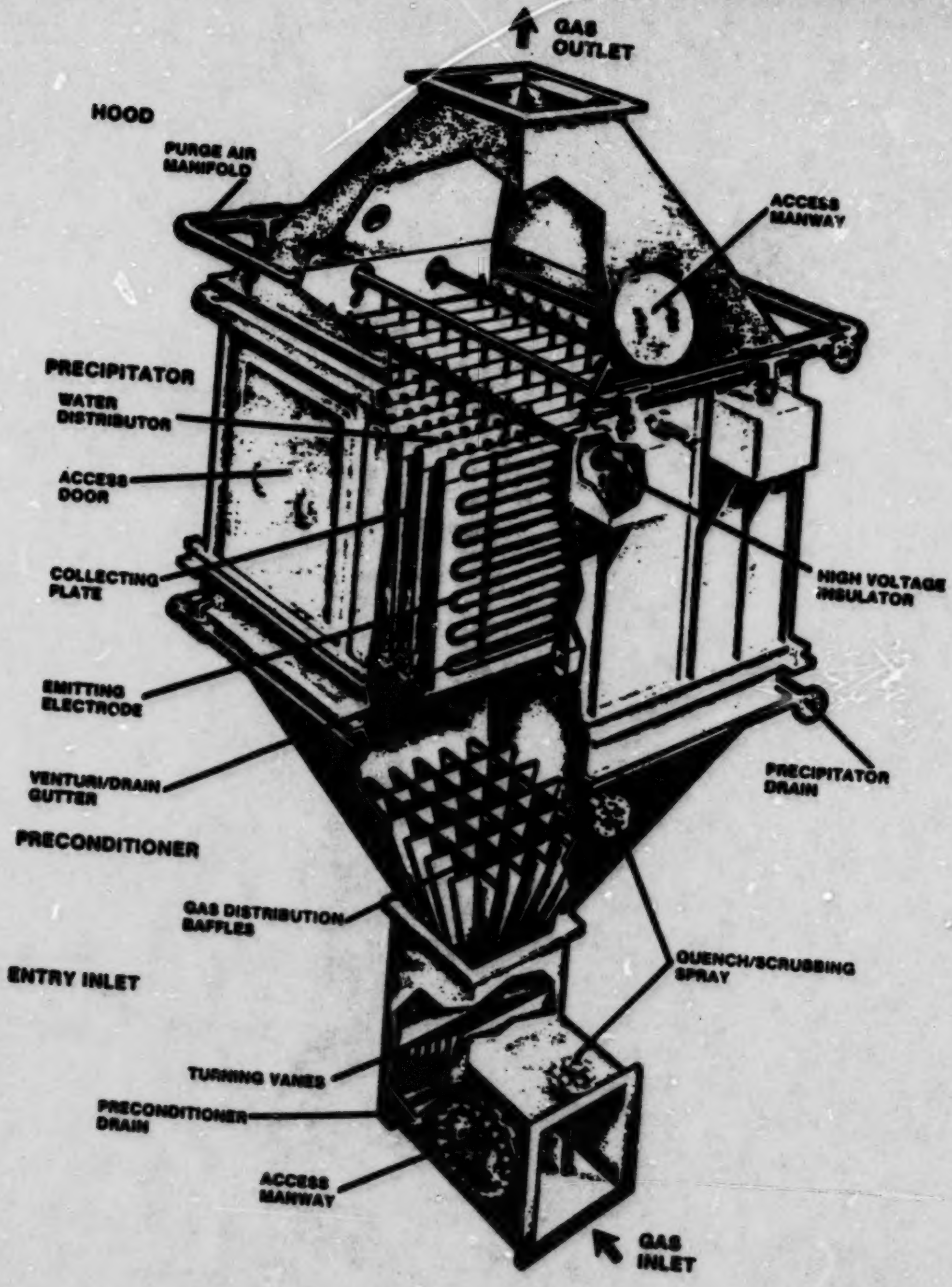

Figure 2-13. Flat-plate-type wet ESP.
(Courtesy of Fluid Ionics, Inc.)

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variety and one of the square or rectangular flat-plate type. Casing can be constructed of steel or FRP, and discharge electrodes can be carbon steel or special alloys, depending on the corrosiveness of the gas stream.

In circular-plate wet ESP's, the circular plates are irrigated continuously; this provides the electrical ground for attracting the particles and also removes them from the plate. It can generally handle flow rates of 30,000 to 100,000 cfm. Preconditioning sprays remove a significant amount of particulate by impaction. Pressure drop through these units usually ranges from 1 to 3 inches of water.

Rectangular flat-plate units operate in basically the same manner as the circular-plate wet ESP's. Water sprays precondition the incoming gas and provide some initial particulate removal. Because the water sprays are located over the top of the electrostatic fields and, collection plates are also continuously irrigated. The collected particulate flows downward into a trough that is sloped to a drain for treatment. The last section of this type of wet ESP is sometimes operated dry to remove entrained water droplets from the gas stream.

The preconditioner liquor and the ESP liquor are generally treated separately so that the cleanest liquor can be returned to the ESP after treatment.

2.2.2 Buyer Responsibilities in ESP Specification and Installation

The buyer should specify the supplier's scope of participation, i.e., to what extent it includes design and furnishing of the material, equipment, and tools necessary to install the ESP (e.g., turnkey or equipment only). The scope may include items that are not specifically mentioned in the specifications but that may be necessary to complete the work. Receiving, unloading, handling, and storage of materials, equipment, and accessories and their complete erection should be covered, as well as a schedule of these events. Startup procedures and return of the site to its original condition should also be addressed.

The buyer should describe the location, provide drawings of the existing system or planned site, and indicate the proposed location of the new ESP's.

The scope should also include the condition of existing gas ducts, breeching, and stacks. In addition, the buyer should provide a list of preferred materials or designs.

The plant engineer should be knowledgeable regarding functional ESP requirements and use this knowledge to follow the design, fabrication, and erection phases of the program. This attention to detail throughout the various phases will pay for itself by reducing the chance of forced shutdown to correct problems that could have been solved before the ESP was constructed and put into operation. The buyer should thoroughly examine the following: 1) the supplier's system standards for fabrication and erection dimensional tolerances; 2) procedures for qualifying the subcontractors; 3) quality control and inspection procedures in the field; 4) the caliber of individuals designated as construction supervisors, advisors, or service engineers; and 5) the organization's work load (to assess the level of competence that will be applied the design and construction of the ESP).[15]

The buyer should also determine what services the seller offers in the way of the training of operators, providing comprehensive O&M manuals (including recommended spare parts), assisting in the actual startup of the new ESP, and providing followup maintenance and/or troubleshooting expertise after the warranty period is over. Although the need for these services will depend on the expertise of the buyer, it is important to determine what the seller is capable of offering.

2.2.3 Component Design, Construction, and Installation Considerations With Respect to Operation and Maintenance

Because ESP components vary greatly among manufacturers, it is impossible to discuss each design. Instead, general information on each component is presented to assist the plant engineer in determining what to look for in the design and installation of various major components.

Structural Sizing--[16]

The use of various techniques for sizing ESP's was discussed in Section 2.1. Once the required collection area has been calculated, one of the first structural parameters to be determined is the width of the ESP. This value depends on the total number of ducts, which is calculated as follows:

$$\text{Total number of ducts} = \frac{\text{acfm}}{(\text{TV})\ (60)\ (\text{PS})\ (\text{PH})} \qquad \text{(Eq. 3)}$$

where acfm = volumetric throughput of gas, actual cubic feet per minute
TV = treatment velocity of gas, ft/s
PS = plate spacing, ft
PH = plate height, ft

Treatment velocity, which is a function of resistivity and particle size of the dust, ranges from 3.0 to 5.5 ft/s in most applications.

The ESP manufacturer determines plate spacing (based on experience with different types of dust) by velocity distribution across the precipitator and by the plate type. Plate spacing usually ranges from 6 to 15 inches, and 9-inch spacing is most common in the United States (weighted wire) and 12 to 14 inches for rigid-type ESP; however, ESP designers are now showing a great deal of interest in larger spacings.

In the selection of plate height, consideration must be given to simultaneously maintaining the required treatment velocity and an adequate aspect ratio and to the limitations posed by structural stability and overall design. Aspect ratio is defined as the ratio of the effective length to the height of gas passage. Although space limitations often determine ESP dimensions, the aspect ratio should be high enough to allow collection of reentrained dust carried forward from inlet and middle sections. In practice, aspect ratios range from 0.5 to 1.5. For efficiencies of 99 percent or higher, the aspect ratio should be at least 1.0 to 1.5 to minimize carryover of collected dust, and some installations may approach 2.0.

The total number of ducts dictates the width of the box. Mechanical sectionalization across the gas flow (parallel) separates the ESP into chambers (each of which can be isolated from the other). Mechanical sectionalization in the direction of gas flow (series) separates the ESP into fields. Figure 2-14 shows both parallel and series mechanical sectionalization.

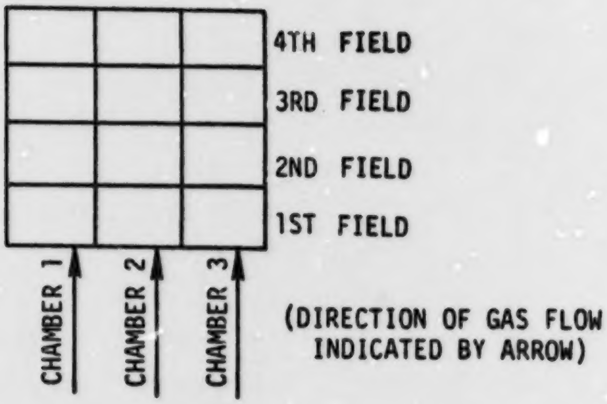

Figure 2-14. Parallel and series sectionalization (mechanical) of an ESP.[16]

Energization and reliability can be improved by limiting the total number of ducts per unit. The number of chambers in an ESP depends on the total number of ducts, as determined from Equation 3. The required number of ESP's depends on the degree of reliability needed, space limitations at the site, and the relative ease of distributing the effluent gas to the ESP's.

The length of the ESP can be calculated by use of the following equation:

$$\text{Treatment length} = \frac{\text{Total collecting plate area}}{(\text{No. of ESP's})(\text{chambers/ESP})(\text{ducts/chamber})(\text{PH})(2)} \qquad \text{(Eq. 4)}$$

The design treatment length is determined by the selection of an integer value of standard section lengths from those offered by the ESP manufacturer. For example, if four sections are required, two of one length and two of another, the structural considerations (such as hopper spans) and some performance criteria determine the positioning of the sections in the direction of the gas flow. The size of the transformer rectifier (T-R) sets is selected to provide lower current density at the inlet, where corona suppression is likely to decrease collection efficiency, and higher current density at the outlet, where although the percentage of fine particles is greater, the overall gas stream is cleaner, which allows high current density.

Mechanical sections result from the chamber and series sectionalization of the ESP. Hopper selection, in turn, is based on the size of these mechanical sections.

Casings--

The ESP's casing is gas-tight and weatherproof. The inlet and outlet connections, the shell, hoppers, inspection doors, and insulator housing are the major casing parts. The shell and insulation housing form a grounded steel chamber that completely encloses all the high-voltage equipment to ensure the safety of personnel.

The casing for most applications is fabricated of a steel suitable for the application (especially for the particular process and heat range). The shell is reinforced to handle maximum positive or negative environmental stresses, such as those imposed by wind, snow, and earthquake. Figure 2-15 shows the typical casing and roof construction.

If inspection and maintenance of both collection and discharge electrode systems are made through the roof casing (usually one door per dust-plate section), as it is in many wire-weight designs, the operator must crawl under the casing stiffeners and over and around the suspension hardware. Because the floor of the crawl space is usually the discharge electrode support system, inspection may be difficult. Thus, if the buyer specifies minimum clearances, he/she will eliminate the tendency among manufacturers (for competitive reasons) to reduce casing, rapper shaft, and suspension hardware costs by providing uncomfortably low headroom.[15] Walkways and access doors between fields are a worthwhile investment for inspection, cleaning, and general maintenance of the ESP's internals, but these additional shell penetrations also increase the potential for inleakage and corrosion.

If the design provides separate insulator compartments, a roof casing covered by insulation, and a walkway surface deck plate, the plate must be watertight and sloped for drainage, and the entire structure must be adequately supported either through rigid insulation or metal framing. Clearances must also be provided for movement of the insulator compartments, rapper shafts, or any other equipment or supports that will move as the ESP casing and structure expand.

The provision of a weather enclosure or superstructure should be encouraged to facilitate routine inspections. Care must be taken to provide for differential movements in the casing and proper ventilation.[15]

Dust Hoppers--

Hoppers collect the precipitated dust and deliver it to a common point for discharge. The most common hoppers are pyramidal and converge to a round or square discharge. If the dust is to be removed by screw conveyor, the hopper usually converges to an elongated opening that runs the length of the

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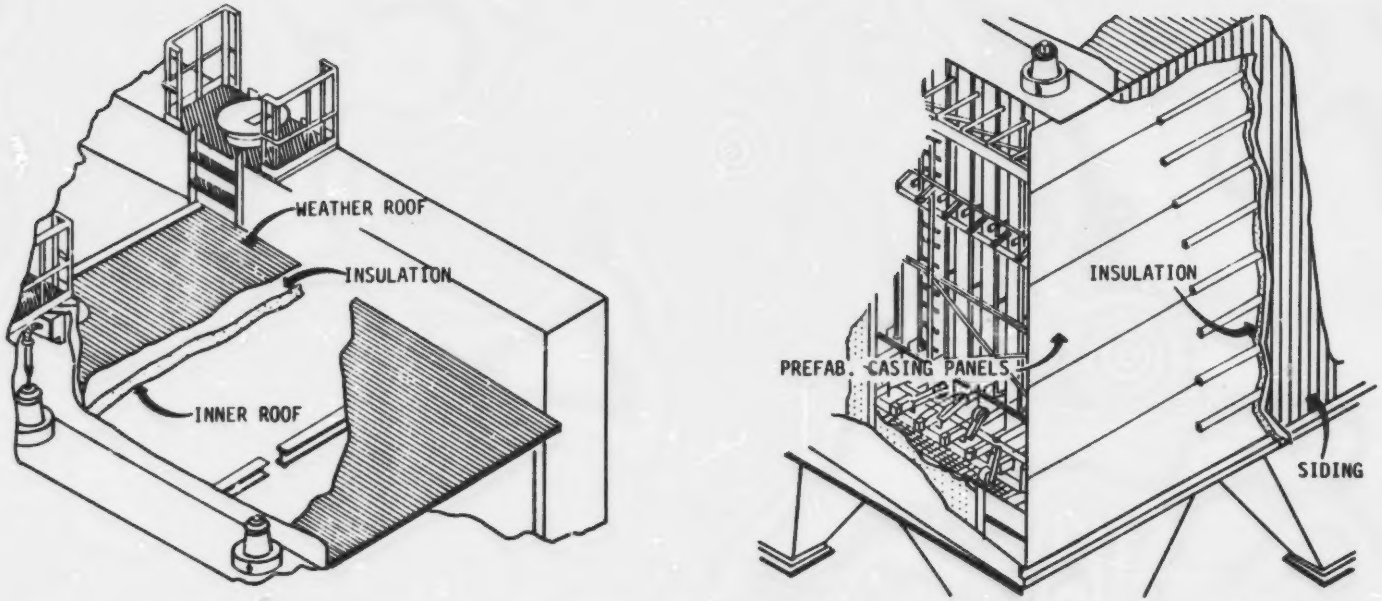

ROOF CONSTRUCTION

CASING CONSTRUCTION

Figure 2-15. Typical roof and casing construction for a rigid-frame ESP.

Source: Wheelabrator-Frye-Lurgi.

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conveyor. Hoppers are not recommended for applications where the dust is very sticky and may build up on sloping surfaces. Instead, the casing should be extended to form a flat-bottomed box under the ESP. The dust is removed by drag conveyors.

Hopper plugging is a major problem. Although manufacturers have produced designs incorporating vibrators, heaters, poke holes, baffles (emphasis on proper location), large discharge flanges, and steep hopper wall angles (55 to 65 degrees) to reduce these problems, they still persist.

A number of improvements could be made in the design of hoppers. The first consideration should be to provide continuous evacuation of the hopper so it will not be used as a storage device. Hopper aspect ratio (height to width) is another important consideration; the correct ratio will minimize reentrainment caused by gas sneakage to the hoppers. Low aspect ratio hoppers can be corrected by vertical baffling.

In the sizing of hoppers, consideration should be given to the fact that 80 to 90 percent of the collected dust is removed in the first field. A conservatively designed dust-removal system will keep pluggage to a minimum. The trend is toward large-sized hoppers so that operators can respond to hopper plugging before electrical grounding or physical damage is done to the electrodes. Although this trend is a valid one, some thought must be given to the time required to remove the accumulated ash. It is probably better not to specify a certain storage time. Stainless steel fillets or lower-end cladding also should be considered to reduce dust bridging in these larger size hoppers.[17]

Some manufacturers offer a high-ash, fail-safe system that automatically phases back or deenergizes high-voltage equipment when high ash levels are detected. Some kind of reliable ash-level detection, either the nuclear or capacitance type, is recommended for all hopper designs. If the preliminary design indicates a potential for problems with ash discharge, the discharge flange should be no less than 12 in. in diameter. Heaters in the discharge throat and up to one-third the height of the hopper have proved to be especially beneficial. A low-temperature probe and alarm also might be considered.

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During construction, checks should be made to determine if the transition from a rectangular hopper to a round outlet is accomplished without ledges or projections; this will help to reduce plugging. Baffles should not extend too far into the hopper (which can increase plugging), and vibrators should be mounted at the baffle line to eliminate the formation of rat holes. The rapping controls should be interlocked with the ash-removal system so that rapping cannot occur unless the hopper is being evacuated.

External key interlocks should be installed to provide safe access to hoppers. Bolt-on doors through baffles should not be installed because they can cause dangerous dust accumulation on the interior side of the door. Enough "poke hole" ports should be provided to allow for cleaning a blockage at the discharge. Enclosing the hopper areas will help to reduce heat loss in the hopper and discharge system. Alignment of conveyors is very important, and depends on the alignment of hopper connections. Field-adjustable flange connections are recommended.[15]

Collecting Electrodes--

Collecting electrodes (plates) are the grounded components on which the dust collects. Many shapes of flat collecting electrodes are used in ESP's, as shown in Figure 2-16. Some ESP's are designed with cylindrical collection surfaces.

Collecting plates are commercially available in lengths of 3 to 12 ft (wire weight), or 6 to greater than 15 ft (rigid frame) and heights of 9 to 36 ft (wire weight) or as high as 50 ft for rigid frame designs. These panels generally are grouped with the ESP to form independently rapped collecting modules. A variety of plates are commercially available, but their functional characteristics do not vary substantially. When assembled, collecting plates should be straight and parallel with the discharge electrodes. Correct alignment requires that care be exercised during fabrication, shipping, storage in the field, and erection.

The plate support system must be rugged because in many designs it must also transmit rapper energy to the plates. Each design should be examined with regard to its operating limits with various types of rappers. The

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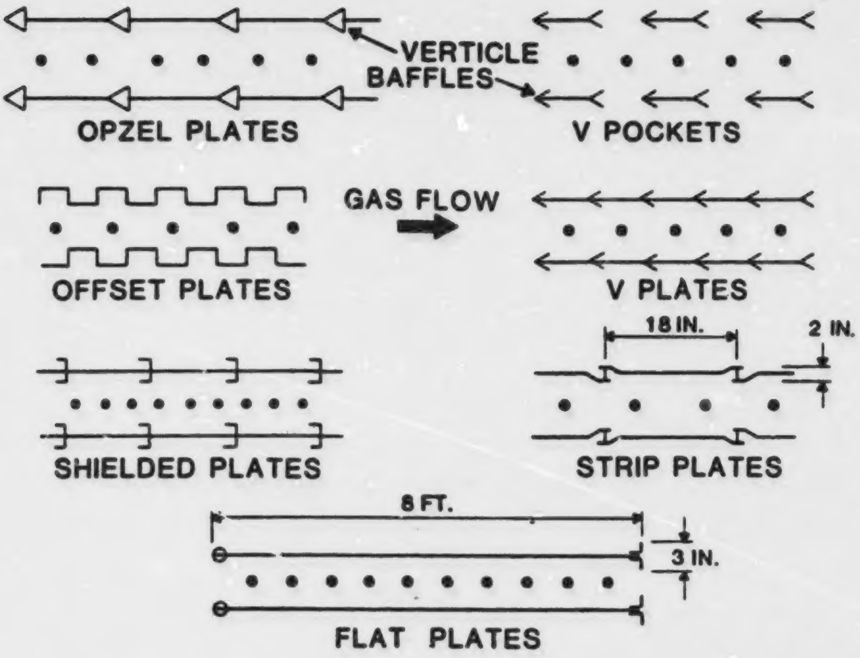

Figure 2-16. Various designs of collecting electrodes.[18]

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effects of vibration and impact loading at all welded points should be considered. Consideration should also be given to the adjustment of any necessary plate alignment after shakedown. Enough spacers should be provided to maintain alignment and allow for temperature variations.

Rapper anvils attached to either plate supports or rapper header beams should be durable enough to withstand the stress of rapping and to maintain alignment (no bending of flanges or other local deformations).

If an ESP is installed properly, collecting plates pose no maintenance problems during normal operation. Replacement or repair of a collecting plate because of warpage or breakage is a time-consuming and expensive task.

The following items should be considered in the erection of collecting plates:[15]

- Collection plate - The trueness of the dust plate depends on the care exercised in fabrication, packaging, storage, and handling in the field. Most damage occurs while plates are being unpacked and raised.
- Collecting plate support structure - The design of this structure must be flexible enough that the structure can be adjusted and readjusted for proper alignment during construction and shakedown. Proper alignment is critical for the rapping anvils.
- Baffles - Baffles are installed between the casing and the outermost collection plate to prevent gas sneakage out of the main zone of precipitation. Enough room should be left for installation and inspection of these baffles to ensure proper closing of the space.

Discharge Electrodes--

Discharge electrodes are metal, and the type is determined by the composition of the gas stream. The electrodes may be cylindrical or square wire, barbed wire, or stamped or formed strips of metal of various configurations (as shown in Figure 2-16). The shape of these electrodes determines the current voltage characteristics; the smaller the wire or the more pointed its surface, the greater the value of current for a given voltage.

Discharge electrodes are mounted in various ways. They may be suspended from an insulating superstructure with weights at the bottom holding them tightly in place, or they may be rigidly mounted on masts or frames. The advantage of the rigid-type discharge electrode system over a wire-weight system is that it lessens the chance of a broken wire falling against a plate and shorting out that section of the ESP. The weighted-wire type must be stabilized to avoid its swinging in the gas stream. Examples of the wire-weight and rigid-wire systems are shown in Figure 2-17.

When properly designed, both wire-weight and rigid-frame discharge electrode configurations have excellent collection capability. The low initial cost of a weighted-wire design is typically offset by high maintenance costs resulting partially from wire breakage. The reverse is true of rigid-frame designs; in this case, the high initial costs are usually offset by low maintenance costs. Warping of the discharge electrode frame caused by wide thermal swings is generally not a problem if a unit is properly designed. Both designs can deliver similar electrical power levels to the ESP for particulate matter collection. Generally, however, rigid-frame ESP's operate at higher voltages and lower current densities than wire-weight ESP's in a given application because of the wider spacing between the discharge electrodes and the collecting electrodes. These voltage-current characteristics may be better suited to collection of high-resistivity dusts.

Because of problems with discharge electrodes design is especially important in areas related to electrical erosion, mechanical fatigue corrosion, and inadequate rapping. When high-current sparks or continuous sparking must be tolerated, the use of large, formed discharge electrodes will provide much better protection against erosion of the discharge electrode than will smaller sizes (of either wire-weight or rigid-frame electrodes). Shrouds should be included at both the top and bottom of wire-weight electrodes, and all interelectrode high-voltage and grounded surfaces should have smooth surfaces to minimize spark-over. Transformer-rectifier sets should be well matched to the ESP load, and automatic spark controllers should keep voltage close to the sparking threshold. Contact between the electrode and the stabilizing frame should be solid to prevent sparking. For rigid-frame discharge electrodes, substantial reinforcement is required at the point where the electrode is attached to the support frame, to ensure that a significant amount of metal must be lost before failure occurs. The use of alloyed metals is recommended for all discharge electrodes to minimize corrosion and fatigue.

Mechanical connections in the discharge electrode structure should be designed so that flexing and reduction in cross-sectional area at junction

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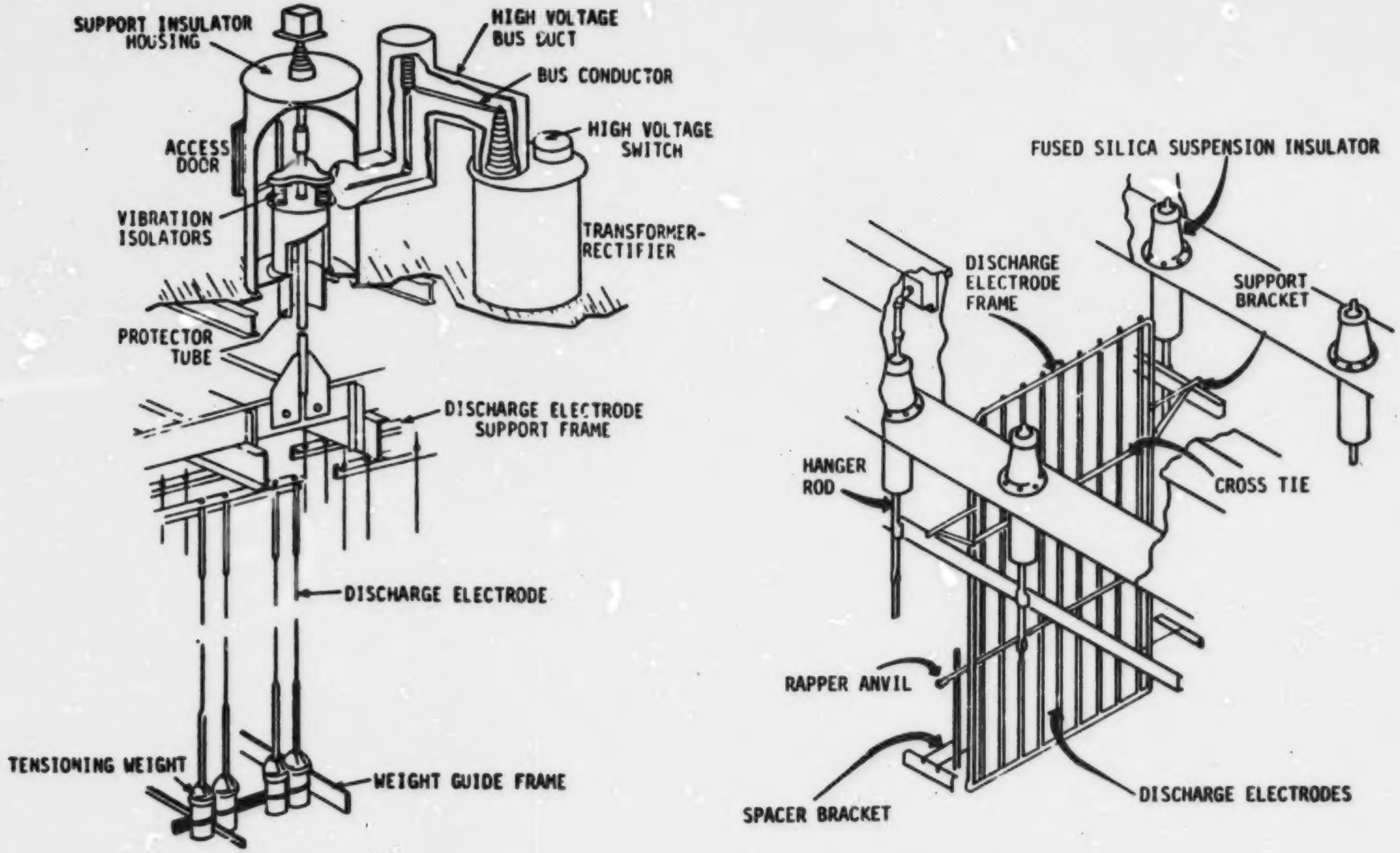


Typical discharge electrode system - penthouse arrangement
(Courtesy of Environmental Elements Co.)

Typical rigid-frame electrode system
(Courtesy of Wheelabrator Frye)

Figure 2-17. Comparison of wire-weight and rigid-frame ESP designs.

points are minimized. Connections should be vibration- and stress-resistant, and electrodes should be allowed to rotate slightly at their mounting points. Keeping the total unbraced length of electrode as short as possible will minimize mechanical fatigue.[17]

Rappers/Vibrators--

Rappers are categorized according to their use on wire-weight or rigid-frame ESP's. On wire-weight ESP's, rapping impulses are provided by either single-impulse or vibratory rappers, which are activated either electrically or pneumatically. Figures 2-18 through 2-20 show examples of typical rappers for wire-weight ESP's.

Electromagnetic or pneumatic impulse-type rappers usually work better on collecting electrodes and in difficult applications because a vibrator generally cannot generate sufficient operating energies without being damaged. The magnetic-impulse, gravity-impact rapper is a solenoid electromagnet consisting of a steel plunger surrounded by a concentric coil; both are enclosed in a watertight steel case. The control unit contains all the components (except the rapper) needed to distribute and control the power to the rappers for optimum precipitation.

During normal operation, a d.c. pulse through the rapper coil supplies the energy to move the steel plunger. The magnetic field of the coil raises the plunger, which is then allowed to fall back and strike a rapper bar connected to the collecting electrodes within the ESP. The shock transmitted to the electrodes dislodges the accumulated dust.

The electromagnetic rappers also have a coil (energized by alternating current). Each time the coil is energized, vibration is transmitted to the high-tension wire-supporting frame and/or collecting plates through a rod. The number of vibrators applied depends on the number of high-tension frames and/or collecting plates in the system. The control unit contains all the components necessary for operation of the vibrators, including a means of adjusting the vibration intensity and the length of the vibration period. Alternating current is supplied to the discharge-wire vibrators through a multiple-cam timer that provides the sequencing and time cycle for energization of the vibrators.

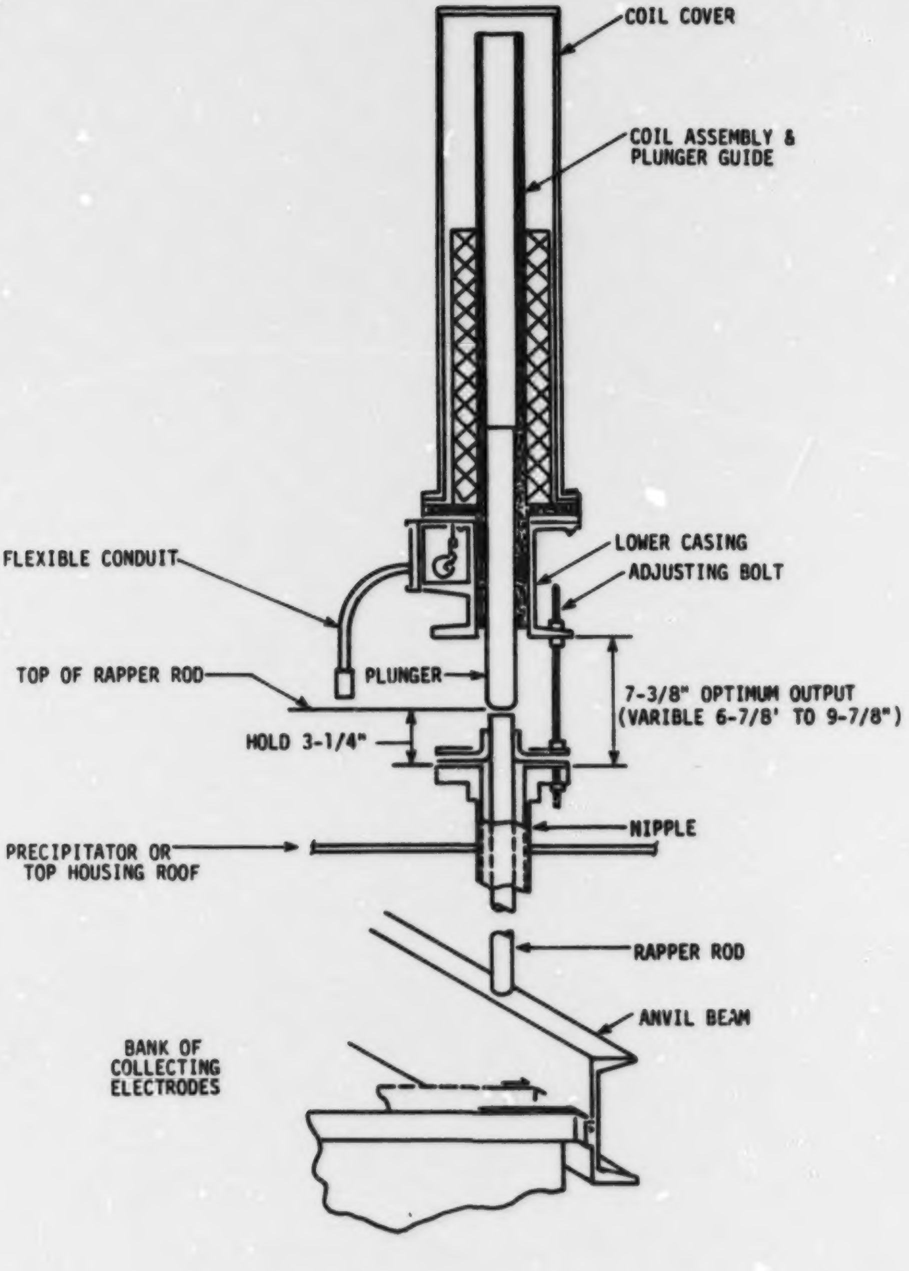
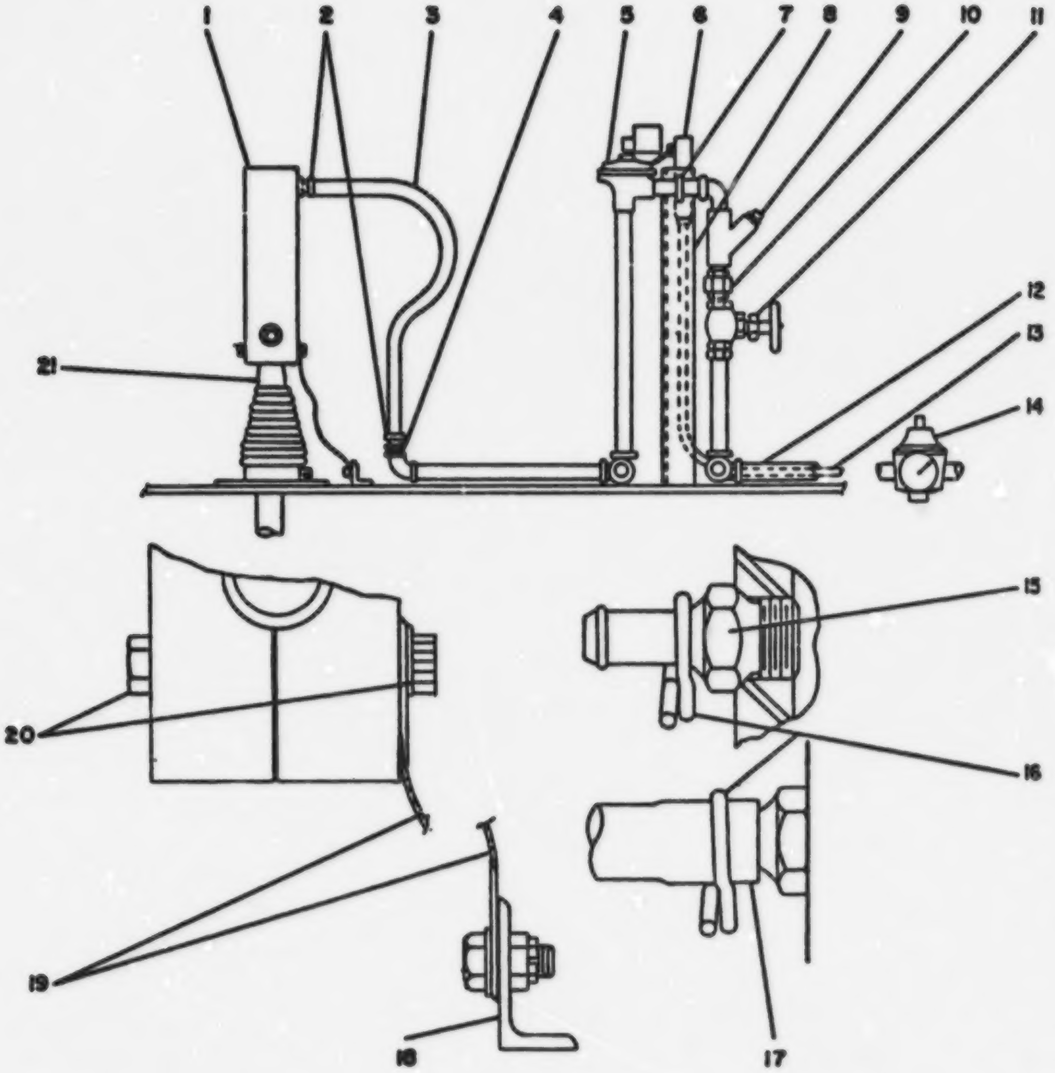

COIL COVER
COIL ASSEMBLY & PLUNGER GUIDE
LOWER CASING
ADJUSTING BOLT
FLEXIBLE CONDUIT
TOP OF RAPPER ROD
PLUNGER
7-3/8" OPTIMUM OUTPUT (VARIBLE 6-7/8' TO 9-7/8")
HOLD 3-1/4"
NIPPLE
PRECIPITATOR OR TOP HOUSING ROOF
RAPPER ROD
ANVIL BEAM
BANK OF COLLECTING ELECTRODES

Figure 2-18. Typical installation of Magnetic Impulse, Gravity Impact (M.I.G.I.) Rapper (courtesy of Environmental Elements Co.).



1. RAPPER ASSEMBLY
2. HOSE CLAMP
3. AIR HOSE
4. AIR HOSE NIPPLE
5. SOLENOID VALVE
6. ELECTRICAL CONNECTOR
7. U-BOLT
8. SUPPORT
9. STRAINER
10. UNION
11. GLOBE VALVE
12. PIPE
13. CONDUIT
14. PRESSURE REGULATOR
15. AIR INLET FITTING
16. SAME AS 2
17. SAME AS 3
18. PRECIPITATOR FRAME
19. GROUND CABLE
20. SCREW AND NUT
21. RAPPER ROD

Figure 2-19. Typical pneumatic rapper assembly.
(Courtesy of Environmental Elements Co.)

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Figure 2-20. Typical electric vibrator type rapper.

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Nonmalleable high-strength alloyed steels should be used for the hardware components because their resonance properties and strengths match those required to receive and deliver impacts with few mechanical failures.[19] The electrical controls should be adjustable so that the rappers can be assembled into different groups and each group can be adjusted independently for optimum rapping frequency and intensity. The controls should be manually adjustable so they can provide adequate release of dust from collecting plates and simultaneously prevent undesirable stack puffing.

Failures of rapper rod connections to carbon steel electrode systems can be minimized by designing welds that are large and strong enough to withstand impacts and by careful welding. Proper selection of rod material and protective shrouding in sealed areas will minimize corrosion problems.

Problems related to ground faults also occur in the ESP's conduit system because of lack of seals at connections, poor-quality wire terminations, and use of low-quality wire.[19]

In some applications, the magnetic-impulse, gravity-impact rapper is also used to clean the ESP's discharge wires. In this case, the rapper energy is imparted to the electrode-supporting frame in the normal manner, but an insulator isolates the rapper from the high voltage of the electrode-supporting frame.

The number of rappers, size of rappers, and rapping frequencies vary according to the manufacturer and the nature of the dust. Generally, one rapper unit is required for 1200 to 1600 ft^2 of collecting area. Discharge electrode rappers serve from 1000 to 7000 ft of wire per rapper. Intensity of rapping generally ranges from about 5 to 50 ft/lb, and rapping intervals are adjustable over a range of approximately 30 to 600 seconds.

Rigid-frame ESP's generally have mechanical-hammer rappers. Each frame is rapped by one hammer assembly mounted on a shaft. (See Figure 2-21.) A low-speed gear motor is linked to the hammer shaft by a drive insulator, fork, and linkage assembly. Rapping intensity is governed by the hammer weight, and rapping frequency is governed by the speed of the shaft rotation.

Acceleration forces in discrete places on the collecting surface plates should be measured and mathematical relationships between hammer weights,

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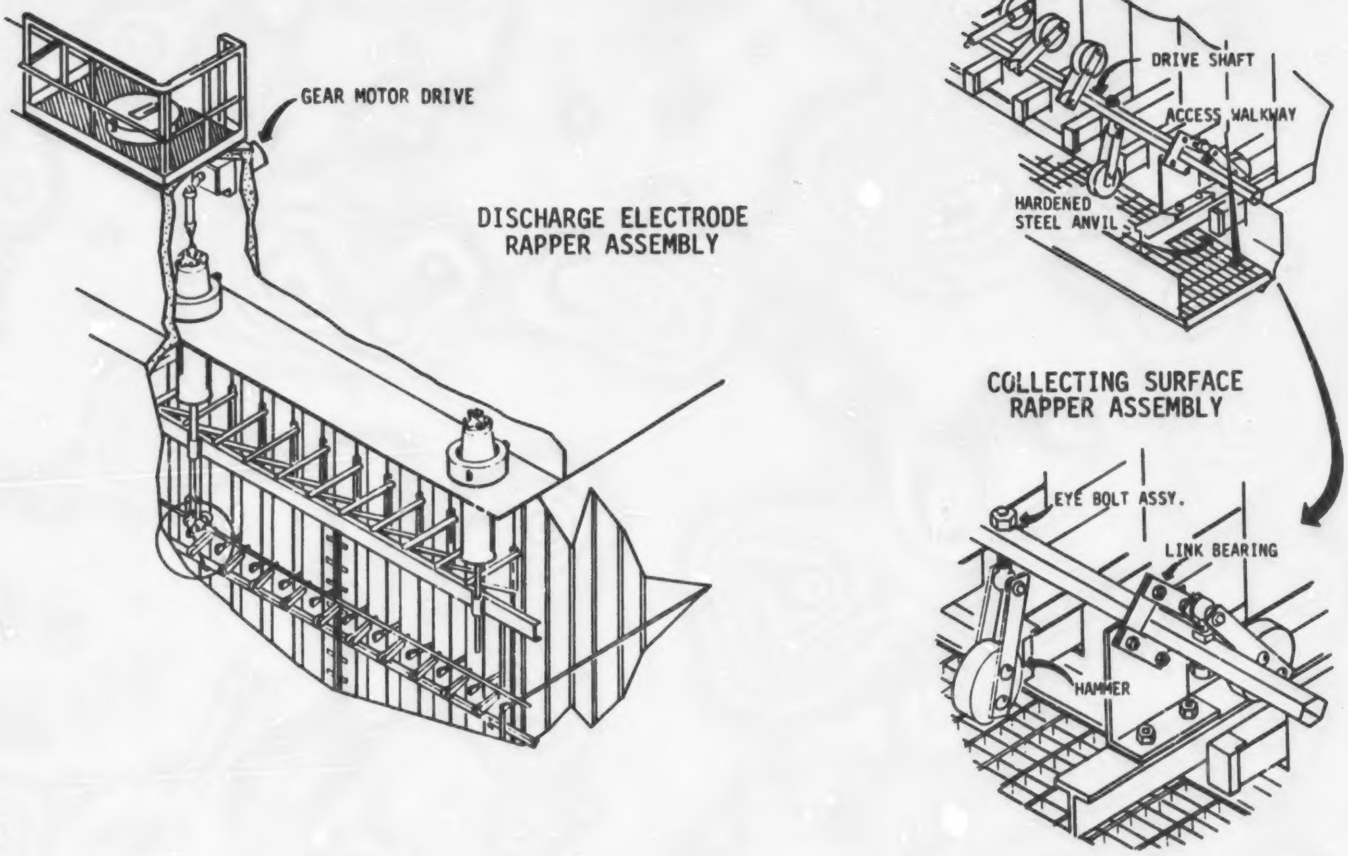

Figure 2-21. Tumbling-hammer assembly for use with rigid-frame discharge electrode and collecting-surface rapping system.
(Courtesy of Wheelabrator Frye, Inc.)

lift angles, and plate dimensions should be established and confirmed in laboratory and field testing. Uniform acceleration on the discharge wire frame is also important for efficient dust removal without the wire being destroyed by its own vibrations.

Solids Removal Equipment--

In large systems such as those in utility applications, solids can be removed from ESP's by a pressure or vacuum system (see Figure 2-22). A screw conveyor can be used for this purpose in many smaller industrial applications. Dust can also be wet-sluiced directly from the hoppers. Once conveyed from the hoppers, the dust can be disposed of dry, or it can be wet-sluiced to a holding pond.

Removal from the hopper--An air seal is required at each hopper discharge. Air locks provide a positive seal, but tipping or air-operated slide-gate check valves are also used for this purpose. The use of heaters, vibrators, and/or diffusers is often considered because of the occasional bridging that occurs in the hoppers. In trough-type hoppers, a paddle-type conveyor provides the best means of transporting the dust to the air lock. Dust valves are often oversized to help facilitate removal of dust from the hopper.

Pneumatic systems--The length of a vacuum system is limited by the configuration of the discharge system and the altitude above sea level. When the limits for vacuum systems are exceeded, pressure systems are applied. When the number of hoppers exceeds about 20 and the length of the system is too great for a vacuum system, combination vacuum/pressure systems may be used.

A vacuum is produced either hydraulically or by use of mechanical vacuum pumps. Positive displacement blowers are used with pressure systems. Vacuum systems are equipped with electric valves and slide gates, whereas pressure systems have air locks and slide gates.

Materials of construction are extremely important in the selection of a solids-removal system. The chemical composition of both the dust and conveying air and the temperatures at various points in the conveying system should be determined.

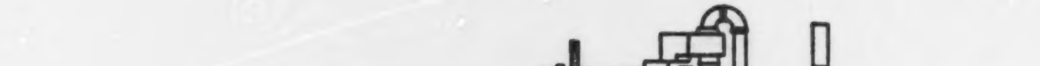

Figure 2-22. Vacuum system for solids removal.

When material characteristics (material density, particle sizes, and concentrations, and the physical characteristics of the conveying air or gas) are known, the required conveying velocity can be determined. Setting the design rate at 20 percent above the theoretical maximum conveying capacity will usually prevent plugging.

Facilities for storing pneumatic dust generally are equipped with cyclones, and often with a fabric filter. The stored dust is conditioned with water and/or a wetting agent and then either transported (by truck or rail) to a disposal site or mixed with water and pumped to a disposal pond.

Gas Distribution Equipment--

Proper gas flow distribution is critical for optimum precipitator performance. Areas of high velocity can cause erosion and reentrainment of dust from collecting surfaces or can allow gas to move through the ESP virtually untreated. Improper distribution of gas flow in ducts leading to the ESP causes dust to accumulate on surfaces and results in high pressure losses.

Devices such as turning vanes, diffusers, baffles, and perforated plates are used to maintain and improve the distribution of the gas flow. A diffuser consists of a woven screen or a thin plate with a regular pattern of small openings. A diffuser breaks large-scale turbulence into many small-scale turbulent zones, which, in turn, decay rapidly and within a short distance coalesce into a relatively low-intensity turbulent flow field. The use of two or three diffusers in series provides better flow than only one diffusion plate could achieve. Cleaning of the gas distribution devices may entail rapping.

The design of inlet and outlet nozzles of ESP plenums and their distribution devices must be uniform. Poor design of inlet plenums can result in pluggage such as that shown in Figure 2-23. Figure 2-24 shows an example of poorly designed inlet plenums. Figure 2-25 shows two methods of improving gas distribution at the inlet plenum.

In multiple-chamber ESP's, louver-type dampers should be used for gas proportioning instead of guillotine shutoff dampers, because guillotine-type dampers tend to destroy proper gas distribution to a chamber.

Figure 2-23. Pluggage of perforated plates at the inlet to an ESP.

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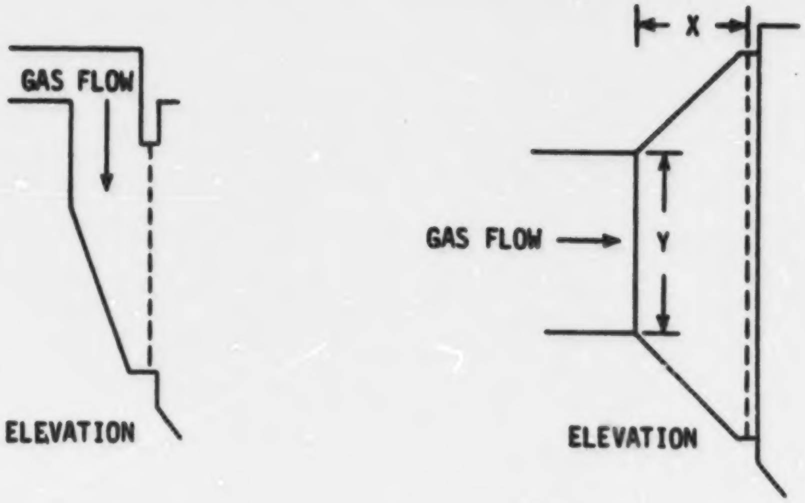

Figure 2-24. Examples of two inlet plenum designs that generally cause gas distribution problems.[20]

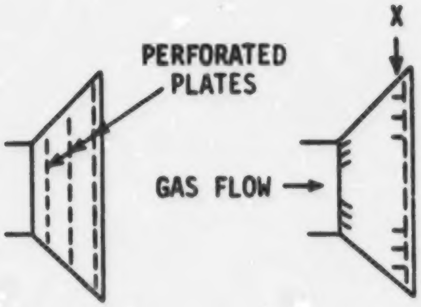

Figure 2-25. Two methods of spreading the gas pattern at expansion inlet plenums.[20]

Poor gas distribution can cause gas sneakage through hoppers. Expansion plenums or top-entry plenums cause gas vectors to be directed toward the hopper; if multiple perforated plates do not fit well in the lower portion of the plenum or if the lower portion has been cut away because of dust buildup, gas is channeled into the hoppers. Bypassing the active collection portion of the ESP and/or reentrainment is the end result.

Gas Flow Models--

Gas flow models are used to determine the location and configuration of gas flow control devices. Although flow model studies are not always able to develop the desired distribution, they can at least provide a qualitative indicator of the distribution.

Temperature and dust loading distributions are also important to efficient ESP operations. Although the temperature of the flue gas is generally assumed to be uniform, this is not always true. The effects of gas temperature on ESP electrical characteristics should be a design consideration, as well as modeling of dust distribution.

If dust loading distributions are not modeled, the dust is assumed to be distributed evenly in the gas; as long as the gas distribution is of a predefined quality, no dust deposition problems should occur. Nevertheless, problems such as poor duct design, poor flow patterns at the inlet nozzle of the ESP plenum, and flow and wall obstructions can cause unexpected dust deposition.[20]

Power Supplies--

The power supply to an ESP consists of four basic components: a step-up transformer, a high-voltage rectifier, a control element, and a control system sensor. The system is designed to provide voltage at the highest level possible without causing arc-over (sustained sparking) between the discharge electrode and the collection surface.

The T-R set converts low-voltage alternating current to high-voltage undirectional current suitable for energizing the ESP. The T-R sets and radio-frequency (RF) choke coils are submerged in a tank filled with a dielectric fluid. The RF chokes are designed to prevent high-frequency transient voltage spikes caused by the ESP from damaging the silicon diode rectifiers. The automatic control system is designed to maintain optimum voltage and current in response to changes in the characteristics and concentrations of the dust. Figure 2-26 shows the components of a typical automatic voltage control system.

The T-R sets should be matched to ESP load. The ESP will perform best when all T-R sets operate at 70 to 100 percent of the rated load without excessive sparking or transient disturbances, which reduce the maximum continuous-load voltage and corona power inputs. Over a wide range of gas temperatures and pressures in different applications, practical operating voltages range from 15 to 80 kV at average corona current densities of 10 to 70 mA/1000 ft^2 of collecting area.

The following are the most common T-R set output ratings:[21]

70 kVp, 45 kV avg. 250 to 1500 mA D.C., 16 to 100 kV, 9- to 10-in. ducts
78 kVp, 50 kV avg. 250 to 1500 mA D.C., 18 to 111 kVa, 11- to 12-in. ducts
80 kVp, 55 kV avg. 250 to 1500 mA D.C., 12-in. ducts (from some vendors)

At currents over 1500 mA, internal impedances of the T-R sets are low, which makes stable automatic control more difficult to achieve. Design should call for the highest possible impedance that is commensurate with the application and performance requirements. With smaller T-R sets, this often means more sectionalization. The high internal impedance of the smaller T-R sets facilitates spark quenching as well as providing more suitable wave forms. Smaller electrical sections localize the effects of electrode misalignment and permit higher voltages in the remaining sections.

High-temperature gases (700° to 800°F) require T-R sets with lower voltage because the density of the gas is lower. High-pressure gases in corona quench situations [high space charge in the interelectrode space; e.g., acid-mist or very wide (15- to 25-in.) ducts] require extra high voltage (lower current ratings than in conventional use); conversely, low gas density and/or low dust concentrations require higher currents at lower voltages. In general, current ratings should increase from inlet to outlet fields (3 to 5 times for many fly ash ESP's).

Generally, name-brand T-R sets rarely fail. Problems are generally related to quality control: defective components; moisture in oil due to

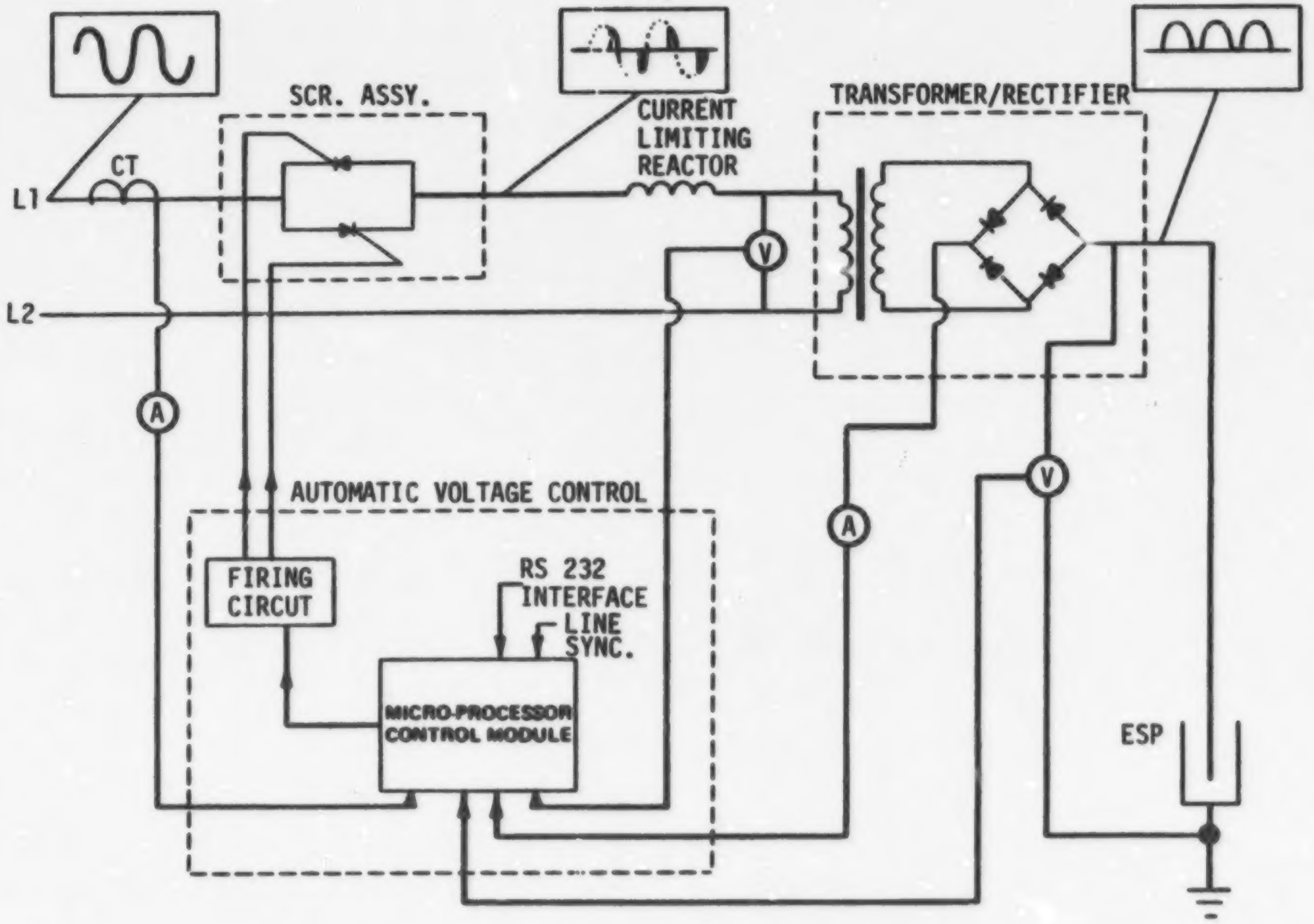

Figure 2-26. Electrostatic precipitator power supply circuit.
(Courtesy of Lodge Cottrell, Inc.)

improper coil baking or vacuum fill techniques; metal bits, rust, or scale in tanks; incompatibility of solid insulation materials with certain cooling liquids; overfilling with oil and insufficient expansion space; poor mechanical bracing or mounting of transformer coils and other components; internal sparking due to inadequate spacing and electrical field concentration points; and mishandling in shipment or installation.[21]

Hand hole-cover plates should be provided for access to rectifiers, radio frequency (RF) diodes, and voltage dividers. Also desirable (and expensive) are large crane trolley systems for quick replacement of T-R sets. Another alternative is to include some additional redundancy of plate area in the design to compensate for T-R set outages.

Silicon-controlled rectifiers should be carefully mounted in suitable heat sink assemblies and tightened with a torque wrench to manufacturer's specifications. All sensitive leads from the T-R sets to the automatic voltage-control cabinet should be shielded in coaxial cable.[21]

Instrumentation--

Instrumentation necessary for proper monitoring of ESP operation can be categorized by location; i.e., T-R sets, rappers/vibrators, hoppers/dust removal systems, and external items.

T-R sets--Power input is the most important measure of the ESP performance. Thus, any new ESP should be equipped with the following:

Primary current meters
Primary voltage meters
Secondary current meters
Secondary voltage meters
Spark rate meter (optional)

These meters are considered essential for performance evaluation and troubleshooting. Figure 2-27 shows a typical control cabinet and T-R set instrumentation.

Data loggers (mainly for digital automatic control systems) are available to help speed up troubleshooting and reduce operating labor. Oscilloscopes are also useful in evaluating power supply performance and identifying the type of sparking (multiple-burst versus single-arc).

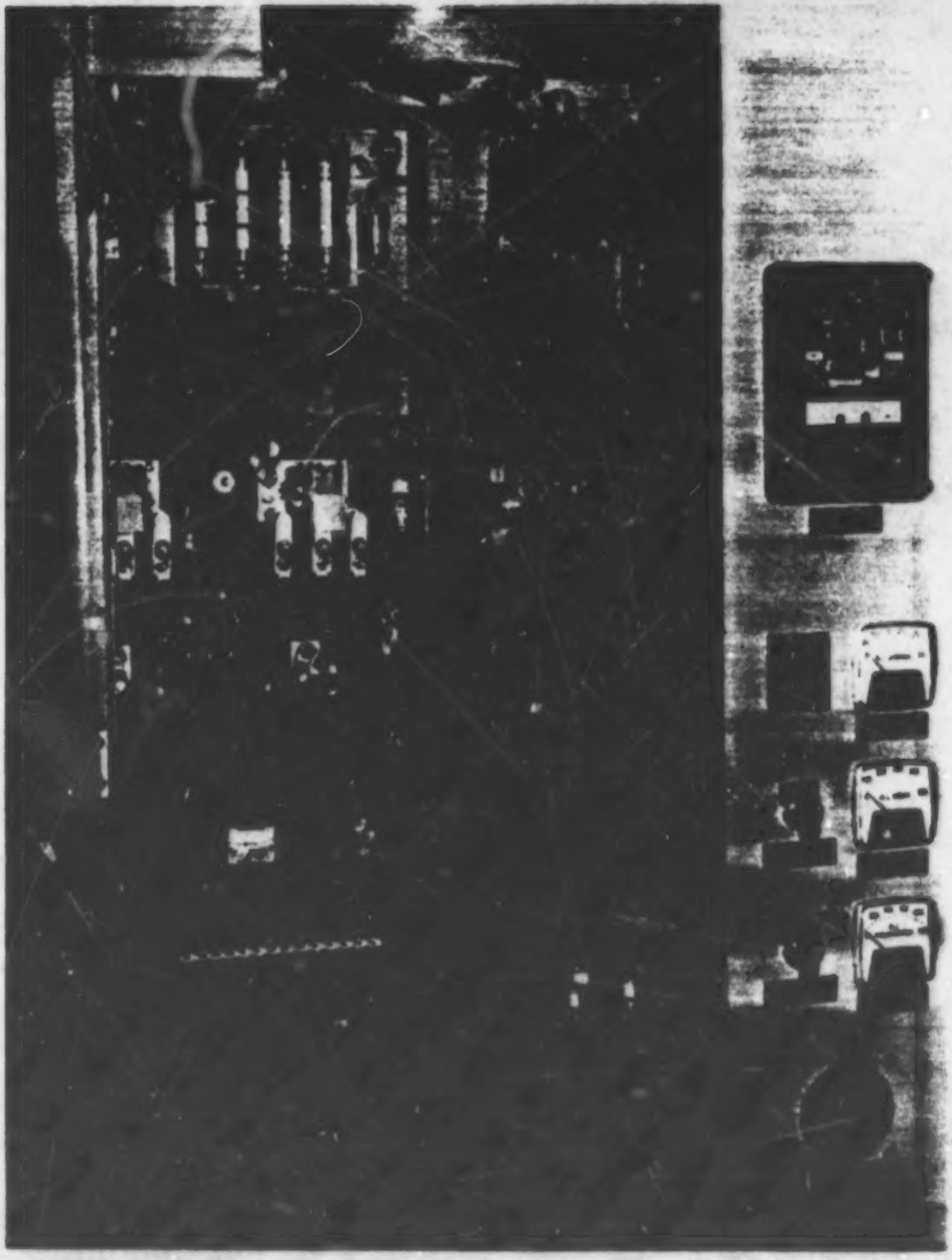

Figure 2-27. Typical ESP control cabinet and T-R set instrumentation.

(Courtesy of Environmental Elements, Inc.)

It is also possible to use feedback signals from transmissometers, full hopper detectors, gas conditioning systems, rappers, and suitable process fault indicators in conjunction with the automatic control unit to achieve optimum performance under all conditions.[22] An example of this is automatic phase-back of T-R sets when hoppers are overfilled, which prevents discharge wires from burning.

Rappers/vibrators--Microprocessor-type technology is available for a high degree of rapper control flexibility and ease of maintenance. For example, new controls can test each circuit before energizing it and thus prevent control damage from ground faults. If a ground fault does occur, the control will automatically bypass the grounded circuit and indicate the problem on a Light Emitting Diode (LED) display.[19] This permits early location of the problem and expedites its solution.

Instrumentation should be used in conjunction with a transmissometer for troubleshooting ESP problems. Separate rapping instrumentation should be provided for each field. In the case of wire-weight electrodes, readings of frequency, intensity, and cycle time can be used with T-R set controls for proper setting of rapper frequency and intensity (see Figure 2-28).

In the case of rigid-frame, mechanical rappers, cycle time and rap frequency of both internal and external rappers are easy to measure. Individual operation of internal rappers is not easily instrumented, nor is intensity control possible without a shutdown of the ESP.

Hoppers--

Instrumentation should be provided for detecting full hoppers, for the operation of the dust valve, and for the dust-removal system. Level detectors can utilize gamma radiation, capacitance, pressure differential, or temperature.[20] Alarms should be located such that hoppers never become completely filled, but frequent alarms should be avoided. A low-temperature probe and alarm can be used in conjunction with the level detector. Control panel lights indicate the operation of hopper heaters and vibrators.[17]

Zero-motion switches are used on rotary air lock valves and on screw conveyors to detect malfunctions. Pressure switches and alarms are normally used to detect operating problems in pneumatic dust handling systems.

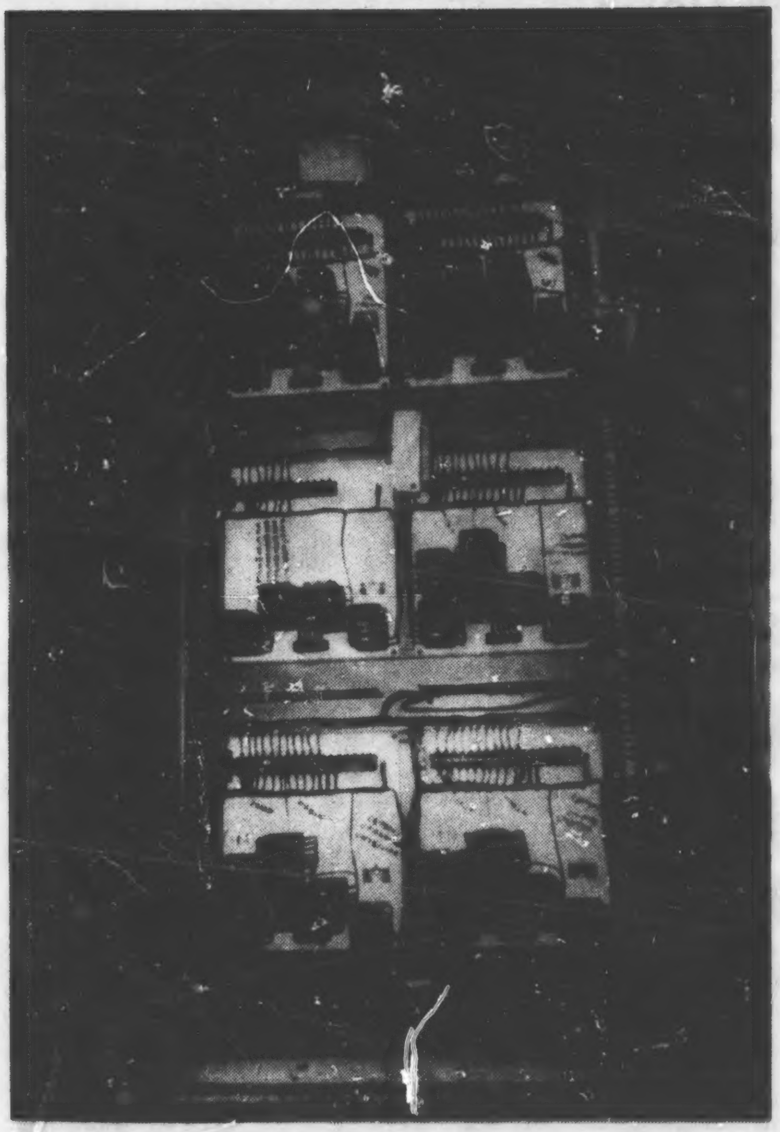

Figure 2-28. Typical rapper control panel (frequency, intensity, and cycle time).

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Accessibility and Safety--

Safe, convenient access (walkways, hatches, etc.) must be provided for entry and servicing of ESP's and ancillary equipment during shutdown. Sometimes the design of the ESP should be such that individual chambers can be prepared for safe entry while the balance of the chambers are on line. Items to which access is needed are discharge wire mountings, hoppers, penthouses, rappers, instrumentation, etc. For rigid-frame ESP's, adequate clearance should be provided between collecting surfaces and interior walkways for the replacement of rigid electrodes through side doors. Access to collection plates and inlet baffles is necessary to allow cleaning during shutdown. Such accessibility requires the proper location of hatches, walkways, ladders, and handrails. Hopper access doors should be wide enough for ladders to be placed in the hoppers, and maintenance personnel should be able to reach the bottom of the discharge electrode frame by ladder from the hopper access platform. All potential electrical shock hazards must be addressed by the use of grounding devices and electrical system lockout procedures. Measures also must be taken to purge enclosures of hot toxic gases before entrance of maintenance personnel.

Erection Sequence--

Usually the casings and hoppers are erected first, and then the collecting surfaces and discharge systems. A good quality control and inspection program must be followed during the erection of an ESP, despite the pressures of construction schedules. If the casing is not erected to true dimensions and attempts are made to compensate for this error during the installation of the collection surfaces, poor alignment of wires and plates can result.[15]

Allowing 2 weeks to a month in the construction schedule for conducting tests of gas velocity and making adjustments in the distribution system (something that is often precluded) will save the time required to make these adjustments after startup.

2.2.4 Areas of Research and Development

Some of the new designs and concepts that have been researched and tested over the past 10 years include 1) wide spacing between discharge and collection electrodes; 2) two-stage charging, i.e., the use of a pre-charging

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electrode or ionizer ahead of the inlet field of the precipitators; and 3) pulse-charging. Researched in the past, these concepts have recently received renewed attention. Each of these technologies is described briefly.

Wide Spacing--

The design of a wide-space ESP is such that the plate-to-plate spacing is in excess of the 9-inch spacing that has been standard in wire-weight ESP's for many years. Spacings of from 10 to 24 inches have been used in Europe and Japan, and more than 160 wide-space ESP's were in operation in Japan at the end of 1978.

Higher voltages are necessary for establishing the electric field in these ESP's, but migration velocities also increase with higher voltages. Thus, some cost savings can be realized because the ESP collection plate area required is smaller, with the wider spacing.

Under normal conditions, a wide-space ESP will operate at about the same current density and have less tendency to spark. Also, minor misalignments will not be as noticeable and additional space is available for inspections.

With high inlet loadings of fine dust, however, the wide-space ESP is more sensitive to space charge effects and excessive sparking may occur, especially in the inlet field.

The design of the wide-space ESP will require higher voltage power supplies, and the optimum bus section size may be different from the standard size because of the higher voltage. The relationship between SCA and collection efficiency will also differ from standard relationships.

Two-Stage Charging--

Two-stage charging is currently being investigated on a pilot-scale level as a possible means of solving the problem of collecting high-resistivity dust. In a two-stage design, the charging and collecting functions are separated. The particles are first charged upstream of the main ESP unit by a precharger or ionizer, and then collected in the main ESP unit by use of a high electric field. The apparent advantage of such an arrangement is the use of a small precharging inlet section and the design of the collector section, which produces a high electric field without generating a corona, and in some cases a lower than normal current density, which thus eliminates back-corona.

Several two-stage designs are currently available and being used in small, low-dust-loading situations such as air conditioning/ventilation systems, condensed oil mists, and other industrial applications in textile, rubber, vinyl, asphalt, carpet, printing, grain drying, and food industries. Current research is directed at extending the two-stage design to handle high dust-loading industrial sources and for improved collection of high-resistivity dusts.[22]

The five main types of precharges now being tested are:

1) The Air Pollution Systems high-intensity ionizer
2) The trielectrode precharger
3) The boxer charger
4) The ion beam charger
5) The cooled-pipe charger

Work is continuing to improve the precharging mechanism and to deal with the problem of keeping a high electric field in the collector section without corona generation (or perhaps low current density for recharging reentrained dust), and the two-stage concept appears to have considerable potential for use in controlling high-resistivity dusts.

Pulse Charging--

Pulse energization has been experimented with in the past few years as a means of upgrading ESP performance on high-resistivity fly ash without adding plate area. In pulse energization, a high-voltage pulse is superimposed on the base voltage to enhance ESP performance on high-resistivity dust. Retrofitting of an existing power supply is relatively simple, and the pulse unit does not require much maintenance.

The lack of performance data on the effectiveness of pulse energization has prevented interested companies from determining how much improvement they can expect. Recent pilot- and full-scale operating data have been analyzed, and a method published for estimating how much improvement can be expected for a given situation.[23]

2.3 ESP O&M CONSIDERATIONS

2.3.1 Typical ESP Failure Modes and Causes of Poor Performance

The several causes of poor performance in an ESP can be divided into the following distinct categories:

1) Fundamental Problems - This category includes gas stream characteristics such as high resistivity; unusually fine particle size, which can be accounted for in the design of the ESP; and overall design inadequacies (poor gas flow distribution, inadequate plate area, inadequate or unstable energization equipment not matched to process characteristics, improper rappers for the process particulate being collected). Because these problems will cause O&M difficulties throughout the life of the ESP, they are essentially independent of a good O&M program. As discussed in Section 2.2, care must be taken during the design and specification of each component of the ESP if the plant O&M personnel are expected to keep the ESP operating within prescribed air pollution control limits. In other words, if the ESP is poorly designed, a proper O&M program may only serve to keep the ESP operating marginally within compliance or at some minimum level above the compliance limit. In these instances, the design-related problem must be corrected before the O&M program can be truly effective.

2) Mechanical Problems - These problems include electrode alignment (i.e., warped plates, close clearances, twisted frames), wire breakage, cracked plates, air inleakage, cracked insulators, dust deposits, and plugged hoppers. Problems such as these will generally be discernible through a review of V-I curves or in the course of routine external or internal inspections. Improper design or construction may contribute to these problems, and efforts should be made to find the cause of the problem instead of blindly replacing the component.

3) Operational Problems - This category of problems includes process upsets that degrade ESP performance, inadequate power input or failure of T-R sets, electrical sections out of service, improper operation or failure of rappers, and dust removal valve failures. These problems also can be influenced by poor design, and the resulting degradation in performance can be immediate or occur over a period of time (e.g., when rappers fail and dust deposits build up on wires or plates).

Also important are the interdependence of the various ESP components and the cascading effect of one problem creating other problems. These considerations are discussed in more detail in later sections.

A well-developed and adequate O&M plan will allow the plant to discover problems before they have a chance to create other, more serious problems. It will also help to determine why certain problems are happening or recurring when the cause of the problem is not immediately obvious. The latter is possible through adequate recordkeeping and the use of these data to develop trends or otherwise isolate reasons for malfunctions or gradual deterioration in performance.

Previous studies have shown performance histories are better at plants where recordkeeping practices are adequate and plant personnel utilize these data than at plants where recordkeeping has received little emphasis.[24] The necessary records for an O&M plan are discussed in the next subsection.

2.3.2 Establishing an Adequate Operation and Maintenance Program

Why should a plant make a concerted effort to maintain its ESP properly? The most convincing reason, outside of the necessity to meet applicable particulate emission regulations, is one of economics. An ESP is an expensive piece of equipment, and even well-designed equipment will deteriorate rapidly if improperly maintained and will have to be replaced long before it should be necessary. Not only can proper O&M save the plant money, it can also contribute to good relations with the local control agency by showing good faith in its efforts to comply with air regulations.

An ESP is unlikely to receive proper O&M without management support and the willingness to provide its employees with proper training. Management must instill an attitude of alert, intelligent attention to the operation of the ESP instead of waiting for a malfunction to occur before acting. This requires a consistent monitoring program entailing the maintenance of detailed documentation of all ESP operations.

Although each plant has its own method of conducting an O&M program, past experience has shown that plants that assign one individual the responsibility of tying all the pieces of the program together operate better than those where different departments look after only a certain portion of the program and have little knowledge of how that portion impacts the overall program. In other words, a plant needs to coordinate the operation,

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maintenance, and troubleshooting components of its program if it expects to be on top of the situation.

Some companies that have several plants have found it to be advantageous to set up a central coordinating office to monitor the O&M status at each plant. The resulting improved communications can provide an opportunity to develop standardized reporting forms, assistance in personnel training, interpretation of operating data, and routine inspections. With knowledgeable people in the central coordinating office, the plants have somewhere to go for assistance in solving problems for their specific kind of ESP.

Another resource that plants can draw upon is the manufacturer's field service engineer. This person is involved in pre-operational inspections to ensure proper assembly of ESP components; to set up the various controls within prescribed limits; to check proper operation, actual energization of the T-R sets, and the dust discharging system; to fine-tune the unit after initial startup; and finally, to instruct plant personnel on how to perform these functions.

Although experienced field service engineers can be very helpful as a resource for assistance in troubleshooting, manufacturers are generally plagued with a high turnover rate. Thus, the plant should be wary of inexperienced people, who may incorrectly diagnose operating problems or be unaware of proper correction procedures. This only adds to the confusion by misleading O&M personnel.

The training and motivation of employees assigned to monitor and maintain the ESP are critical factors. These duties should not be assigned to inexperienced people who do not understand how the ESP works or the purpose behind their assigned tasks. The employee must know what management expects and should receive encouragement for a job well done.

Regular training courses should be held by in-house personnel or by the use of outside expertise so that operators and maintenance personnel are instructed on everything they need to know in regard to the ESP. This should include written instructions and "hands-on" sessions on safety, how to make inspections while the ESP is both in and out of service, how to take electrical readings, perform routine maintenance, investigate grounds or other

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problems, and how to record and use data. Training provides the knowledge necessary for proper operation and maintenance of the ESP and makes the employees' job easier because they will understand why they are taking electrical readings or searching for broken wires.

In summary, the three separate components of an adequate plan for long ESP life are operation, maintenance, and troubleshooting. Each plant should have its own O&M procedures manuals, blueprints, and a complete set of ESP specifications; an adequate supply and record of spare parts; written procedures for addressing malfunctions; and formalized audit procedures.

Records should be kept on ESP operating conditions (process logs, fuel records, gas temperature, ESP power levels, etc.), equipment conditions (internal inspections; daily inspections of rappers, hoppers, T-R set trips, etc.), maintenance (work orders, current work in progress, deferred work), and troubleshooting/diagnostic analysis (component failure frequency and locations, impact of process changes on ESP performance, and other trend-related analyses). Each of these areas is discussed in detail in later sections of this manual.

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SECTION 3
ESP PERFORMANCE MONITORING

Performance monitoring is a key factor in establishing good operation and maintenance procedures for an ESP. It includes measurement of key operating parameters by both continuous and intermittent methods, comparison of these parameters with baseline and/or design values, and the establishment of recordkeeping practices. These monitoring data are useful in performance evaluation and problem diagnosis. In this section, the key operating data and procedures used in performance monitoring are discussed. Interpretation of the data is covered in Section 4.

3.1 KEY OPERATING PARAMETERS AND THEIR MEASUREMENT

Several operating parameters are indicative of a likely change in performance. Some of these parameters are easily measured and monitored on a continuous basis, whereas others must be measured only periodically because of the expense and/or difficulty in measurement. Most of these parameters, however, directly affect ESP performance. The following typical parameters are discussed here: gas volume and gas velocity through the ESP; temperature, moisture, and chemical composition of the gas; particle size distribution and concentration; resistivity of the particulate; and power input. Many of these factors are interrelated.

3.1.1 Gas Volume and Velocity

According to predictive equations and models, a decrease in gas volume results in an increase in collection efficiency and vice versa. Although the improvement or deterioration in performance is not nearly as great as the Deutsch-Anderson equation predicts, the equation is qualitatively correct. A decrease in gas volume results in an increase of the SCA (ft^2 of plate area/ 1000 acfm), a decrease in gas velocity through the ESP, an increase in the

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treatment time (during which the particulate is subjected to the electric field charging and collecting mechanisms), and hence, improved performance. A decrease in velocity may also reduce rapping reentrainment and enhance the collection of the fine particles in the 0.1 to 1.0 μm range, which are exceptionally difficult for most ESP's to collect.

Gas flow distribution is a very important aspect of gas flow through the ESP. Ideally, the gas flow distribution should be uniform throughout the ESP (top to bottom, side to side). Actually, however, gas flow through the ESP is not evenly distributed, and ESP manufacturers settle for what they consider an acceptable variation. (Standards recommended by the Industrial Gas Cleaning Institute have been set for gas flow distribution. Based on a velocity sampling routine, 85 percent of the points should be within 15 percent of the average velocity and 99 percent should be within 1.4 times the average velocity.) Generally, uneven gas flow through the ESP results in lost performance because the reduction in collection efficiency in areas of high gas flow is not compensated for by the improved performance in areas of lower flow. Gas distribution can also affect gas sneakage through the ESP. The use of gas distribution devices such as perforated plates and turning vanes and good ductwork design help to provide good gas distribution.

Total gas volume is usually measured by using a pitot tube traverse. The method is usually a combination of EPA Reference Methods 1 and 2; the duct is divided into equal areas, and each area is sampled to arrive at an average velocity through the duct. When the average velocity and the duct cross-sectional area are known, the average gas volume can be determined. Because most facilities do not routinely measure gas volume, other indirect indicators may be used to estimate the volume. These include fan operating parameters, production rate, and a combination of other gas condition parameters. Because gas volume is not routinely monitored, neither is the actual SCA on a day-to-day basis.

Measurement of gas flow distribution through the ESP is even less common. Because the flow measurements are obtained in the ESP rather than the ductwork (where total gas volumetric flow rates are usually measured), more sensitive instrumentation is needed for the low gas velocities. The instrument typically specified is a calibrated hot-wire anemometer. The anemometer test is usually performed at the inlet and outlet of the ESP, but occasionally they are performed at some mid-point between the inlet and outlet (usually between two fields). Care must be taken to assure that internal ESP structural members do not interfere with the sampling points.

Gas flow distribution tests are conducted when the process is inoperative and the ESP and ductwork are relatively cool. This often limits the amount of gas volume that can be drawn through the ESP to less than 50 percent of the normal operating flow; however, the relative velocities at each point are assumed to remain the same throughout the normal operating range of the ESP. A large number of points are sampled by this technique. The actual number depends upon the ESP design, but 200 to 500 individual readings per ESP are not unusual. With a good sampling protocol, any severe variations should become readily apparent.

3.1.2 Gas Temperature

Monitoring the temperature of the gas stream can provide useful information about the performance of an ESP and can provide useful clues for diagnosing both ESP performance and process operating conditions. The major concern in temperature measurement is to avoid sampling at a stratified point where the measured temperature is not representative of the bulk gas flow. Thermocouples with digital, analog, or strip chart display are typical.

The effect of temperature is most important as it relates to the resistivity of the particulate and as an indicator of excessive inleakage into the gas stream. In moderately sized ESP's, changes in dust resistivity can produce large changes in performance (as evidenced by power input to the ESP and opacity readings). In some cases, when the resistivity versus temperature curve is steep, a change of only 10° to 15°F may substantially change ESP performance because it causes a shift in resistivity. This is particularly true where high resistivity is a problem (recall Figure 2-3). Lowering the temperature slightly to increase condensation or adsorption of surface conductivity-enhancing materials is usually one available option, if neither corrosion nor sticky particles pose a problem.

Temperature can also affect gas properties to such an extent that they will change the relative levels of voltage and current and the density and viscosity of the gas stream, which affect particle migration parameters.

These effects, however, may go unnoticed on many precipitators, as resistivity effects may overshadow them.

Lastly, comparison of inlet and outlet temperatures may be useful in the diagnosis of excessive inleakage into the ESP. Even the best constructed and insulated ESP will experience some temperature drop, which can range from 1° to 2°F on smaller ESP's or up to 25°F on very large ESP's. In any case, some acceptable difference or maximum differential should be set, and when exceeded, this should be an indicator of improper operation or a maintenance problem that must be corrected.

3.1.3 Chemical Composition and Moisture

The chemical composition of both the particulate entering the ESP and the flue gas can affect ESP performance, although in somewhat different ways. In many process applications, either the gas composition or key indicators of gas composition are usually available on a continuous or real-time basis. Chemical composition of the particulate matter, however, is often not available except on an intermittent, grab-sample basis.

The operation of an ESP depends on electronegative gases (such as oxygen, water vapor, carbon dioxide, and sulfur dioxide/trioxide) to generate an effective corona and to transport the electrons from the discharge electrode to the collection plate. The presence of one or more of these gases is necessary to enhance the ESP performance, and the relative level in the gas stream is not always important to ESP operation. Levels of CO_2 or O_2, however, are often monitored on combustion sources as a measure of excess air and combustion efficiency and not as an indicator of the potential ESP operation. In most processes, these electronegative gases are available and are not a direct concern to operators.

The presence of water vapor and/or acid gases may prove useful as resistivity modifiers or conditioners, and they may be necessary for proper ESP performance. On the other hand, they may cause a sticky particulate that is difficult to remove (see Appendix B, Kraft Pulp Recovery Boiler for discussion of SO_2 generation as an example).

The chemical composition of the particulate matter also influences ESP performance. Specifically, it greatly influences the range of resistivity with which the ESP will have to operate. The presence of certain compounds

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such as alkalies, calcium, or other components can be used to predict resistivity problems. In addition, chemical composition can change with particle size, which may change ESP performance at the inlet, mid, and outlet sections and further complicate prediction of ESP performance on a day-to-day basis.

From a practical standpoint, the chemical composition of the dust and gas stream is a dynamic quantity, and any monitoring scheme may only point out an optimum range and the variability. Monitoring the level of certain compounds may prove useful in some instances; for example, in the combustion of coal, sulfur content, combustibles content, and chemical composition of the ash may provide supporting evidence when problems occur. In many instances, however, chemical composition is either not monitored or it is monitored for other purposes.

3.1.4 Particle Concentrations and Size Distribution

Electrostatic precipitators can be designed for a wide range of mass loadings to provide satisfactory performance when combined with other operating and design parameters. They have been designed to collect loadings from several tenths of a grain per actual cubic feet of gas to values exceeding 100 gr/acf. Within limitations, changes in the mass loading do not seriously affect an ESP's performance, although some changes in outlet concentration can occur. Other factors (e.g., design values of SCA, superficial velocity, and electrical sectionalization and such physical properties as resistivity and particle size distribution) are usually more important to ESP performance when mass loading changes occur.

Mass loading at the inlet and outlet of the ESP is usually measured by standard EPA reference methods. The difference between the amount of material in the outlet gas stream and the inlet gas stream provides the basis for removal efficiency calculations. The use of the reference sampling methods, however, can be difficult on very-high-efficiency ESP's or on ESP's serving processes that generate very high mass loadings at the inlet. When outlet mass loadings are very low, long sampling times may be required to collect enough material to be weighed accurately. Also, simultaneous sampling of inlet loadings during the entire test period may not always be possible if the loadings are so high that the sampling train becomes overloaded. In some instances, a series of probes inserted for 1 to 15 minutes to take "grab"

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samples of the inlet concentration may be all that is technically possible. Although this may not provide as accurate a value for inlet mass loading as would an "integrated" sample taken concurrently with the outlet emissions test, it will give a reasonable value to work with.

As previously mentioned, a change in mass loading may have little effect on ESP performance compared with the importance of other parameters. Nevertheless, a discussion of loading effects on ESP performance would not be complete without a discussion of the effects of particle size distribution.

The particle charging mechanisms were discussed in Section 2. In the particle size ranges where field charging dominates (above 1 μm) and diffusion charging dominates (below 0.1 μm), the ESP usually performs reasonably well. It is in this region between 0.1 and 1.0 μm, however, that most ESP's have difficulty collecting particulate because neither charging mechanism dominates. The minimum ESP collection efficiency is usually on particles between 0.4 and 0.8 μm in diameter. Thus, if a change in loading is also accompanied by a change in particle size distribution, the magnitude of these combined changes must be evaluated to predict ESP performance. In many instances a shift in particle distribution toward the 0.1 to 1.0 μm range could be detrimental to ESP performance even though the mass loading decreases, because these particles are lighter than 5, 10, or 50 μm particles. In other words, the total weight entering the ESP can decrease while the number of particles actually increase, and this increase in the number of particles can be detrimental to ESP performance if excessive numbers are in the 0.1 to 1.0 μm range.

Particle size distribution is usually determined through the use of cascade impactors. Various types of cascade impactors are available with different particle cut sizes and for different loadings. A typical cascade impactor system is presented in Figure 3-1. The cascade impactor is usually placed on a standard sampling probe and inserted into the gas stream for isokinetic sampling of the particulate. A sampling train with a cascade impactor is illustrated in Figure 3-2. After sampling is completed, each stage of the impactor is weighed in the lab and compared against its initial weight to determine distribution. Because the impactor consists of several stages (usually 5 to 9) and each stage corresponds to a progressively smaller

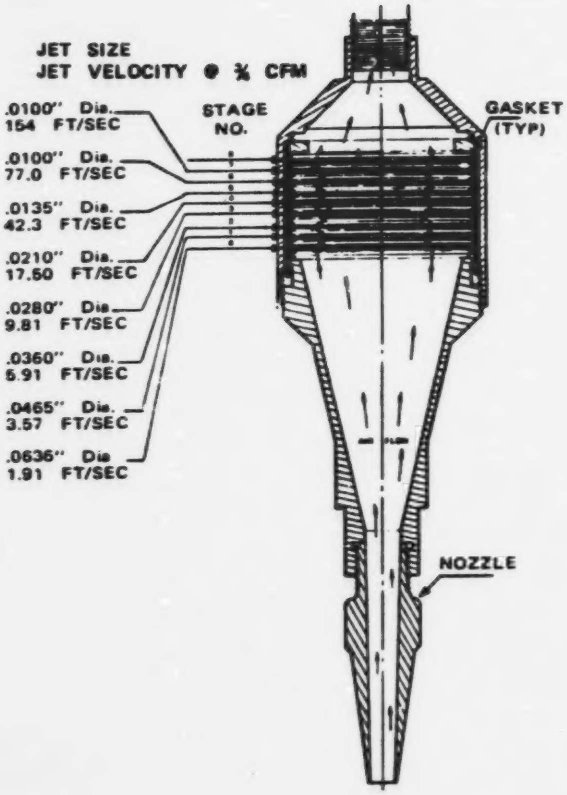

Figure 3-1. Typical cascade impactor system (courtesy of Andersen Samplers, Inc.).

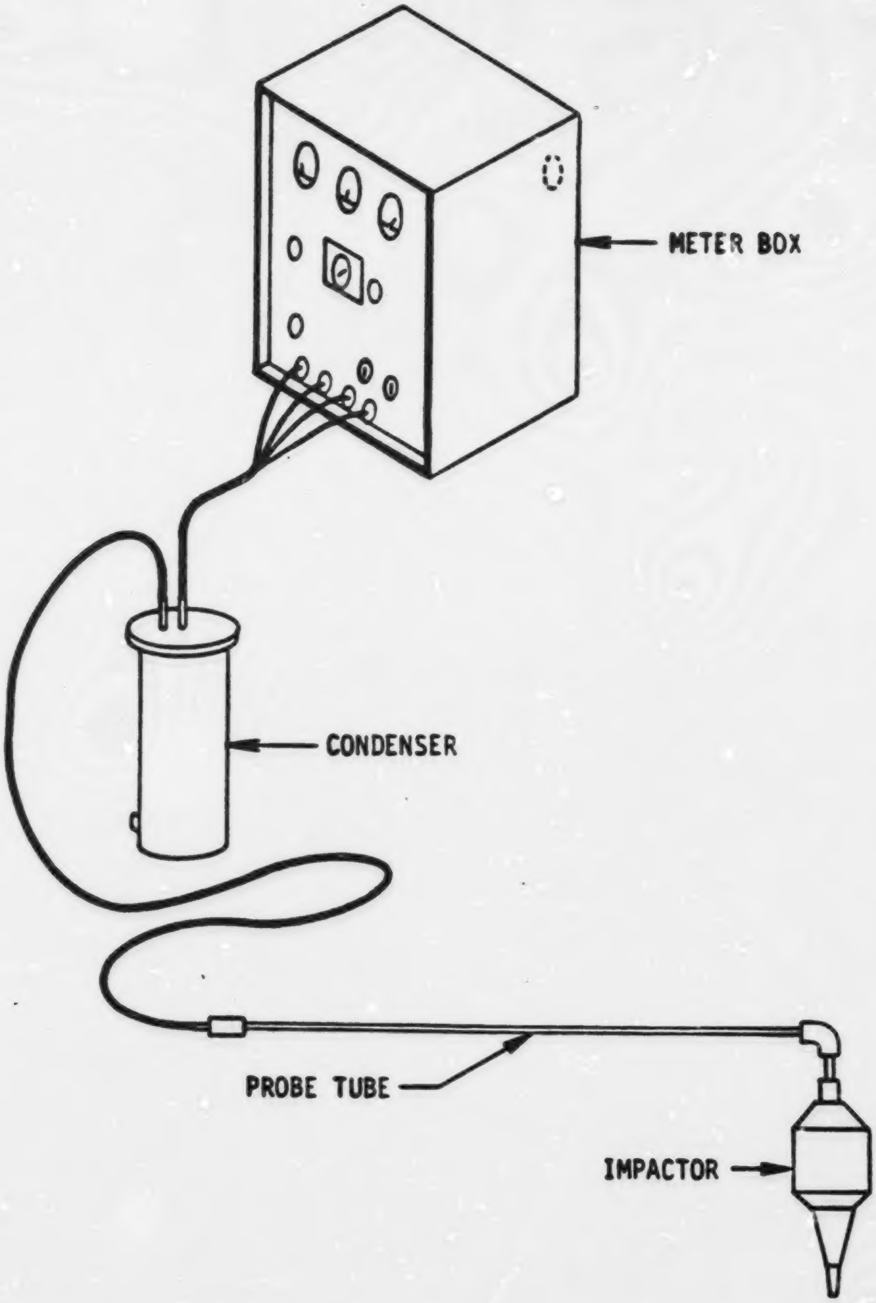

Figure 3-2. Sampling train with cascade impactor.

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particle size range, the weight gain of each successive stage provides a weight distribution of particle sizes.

Cascade impactors have two limitations: the flow rate cannot be varied during the test run, and multiple-point samples are not usually possible on a single sample train. The careful selection of sampling location is required to avoid errors caused by stratification and to provide the representative sample necessary for obtaining valid results. The particle capture characteristics of a cascade impactor are calibrated against a given flow rate. Thus, the stated particle size range for any given stage in the impactor is referenced against a fixed flow rate. Changes in the reference flow rate to provide isokinetic sampling in the stack will change the particle size range that each impactor stage will capture. If the chosen flow rate is different from the reference value, calibration curves are available for each impactor to correct for changes in the particle size sensitivity of each impactor stage. Thus, the flow rate through the impactor cannot be changed once it has been established. This necessitates single-point sampling, which is essentially a grab sample. The situation is even worse at the inlet, where sample times may be limited to only 1 to 2 minutes because of mass loading. More than a single-point sample may be obtained by the use of multiple cascade impactors to sample a number of different points. This is both equipment- and labor-intensive; however, it may provide an indication of the representative nature of a single-point sample. In some instances, sampling at an "average" isokinetic rate is used for traverses.

3.1.5 Resistivity of Particulates

The particulate resistivity is important to the control of the electrical characteristics of the ESP. Whereas resistivity has little to do with how much charge a particle will accept (that is related to particle size), it is a controlling factor in how much voltage and current are applied in each field of the ESP. The voltage and current levels determine the migration rate of charged particles and the charging rate of the particulate matter. Resistivity primarily affects the plate. When resistivity is outside of a very narrow range, ESP performance deteriorates. The optimum resistivity range is typically 10^8 to 10^{10} ohm-cm.

The resistivity of a given dust is usually controlled by its chemical composition, the composition of the gas stream (particularly the presence of conditioning agents such as water vapor, SO_3 HCl, etc.), and the gas stream temperature. Resistivity is generally not a function of particle size although some slight effects may be apparent between large and small particles due to compaction on the plate. The resistivity of large and small particles can be substantially different, however, if their compositions are significantly different as a result of process operating characteristics. The resistivity of a dust is not a static quantity; it varies with process conditions and feed characteristics. Designers of an ESP can only hope that the resistivity will stay within a relatively narrow range over the life of the unit.

Dust resistivity is usually measured at the ESP inlet by one of two methods: in situ and laboratory (bulk) measurement. In situ methods usually involve collecting the particulate under actual gas stream conditions, measuring changes in the voltage/current characteristics for comparison with clean conditions, and using these changes to determine dust resistivity. The limitations of this method are that resistivity changes due to temperature cannot be measured and actual dust layer thickness is difficult to measure. Bulk measurement takes place in the lab after an isokinetic dust sample is collected and prepared. The difficulty with the bulk measurement method is that actual gas and particulate conditions cannot be duplicated; however, a resistivity-versus-temperature profile can be obtained with this method. The resistivity value obtained by two methods can differ by one order of magnitude or more. The value of resistivity obtained by a point-to-plane in situ method is probably more representative of the actual dust resistivity, but both methods provide some indication of resistivity.

3.1.6 Power Input

The power input to the ESP can be a useful parameter in monitoring ESP performance. The value of power input for each field and for the total ESP indicates how much work is being done to collect the particulate. In most situations, the use of power input as a monitoring parameter can help in the evaluation of ESP performance, but some caution must be exercised.

The T-R's of most modern ESP's are equipped with primary voltage and current meters on the low-voltage (a.c.) side of the transformer and secondary voltage and current meters on the high-voltage rectified (d.c.) side of the transformer. The terms primary and secondary refer to the side of the transformer that is being monitored; the input side is the primary side of the transformer. Older models may have only primary meters and, perhaps, secondary current meters. When both voltage and current meters are available on the T-R control cabinet, the power input can be estimated. Each T-R meter reading must be recorded.

When only the primary meters are available, the values for a.c. voltage and current are recorded and multiplied; however, when secondary meters are available, d.c. kilovolts and milliamps also should be recorded and multiplied. When both primary meters and secondary meters are available, the products of voltage and current should be compared. These values represent the number of watts being drawn by the ESP; in all cases, the secondary power output (in watts) is less than the primary power input to the T-R. The primary and secondary meter values should not be multiplied; however, this is done occasionally to aid in the evaluation of the ESP performance (e.g., primary voltage to secondary current).

The power inputs calculated for each T-R set and for the ESP do not represent the true power entering the T-R or the effective power entering the ESP; however, they are sufficiently accurate for the purpose of monitoring and evaluating ESP performance. These values indicate just how well each of the sections is working when compared with the actual voltage and current characteristics. The ratio of secondary power (obtained from the product of the secondary meter readings) to the primary power input will usually range from 0.5 to 0.9; the overall average for most ESP's is between 0.70 and 0.75. In general, as the operating current approaches the rated current of the T-R it appears to be more efficient in its utilization of power. This is due to a number of factors, including SCR conduction time, resistance of the dust layer, and capacitance of the ESP. The actual voltage and current readings that are used to calculate power will be controlled by the gas composition, dust composition, gas temperature, and physical arrangement within the ESP. Thus, as one moves from inlet fields towards outlet fields, the apparent

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secondary power/primary power ratio increases in most ESP's because the ESP's tend to operate to their rated current output. When ESP's only have primary voltage and current meters, the power input may be estimated by obtaining the multiplication product.

3.2 INSTRUMENTATION SYSTEMS AND COMPONENTS

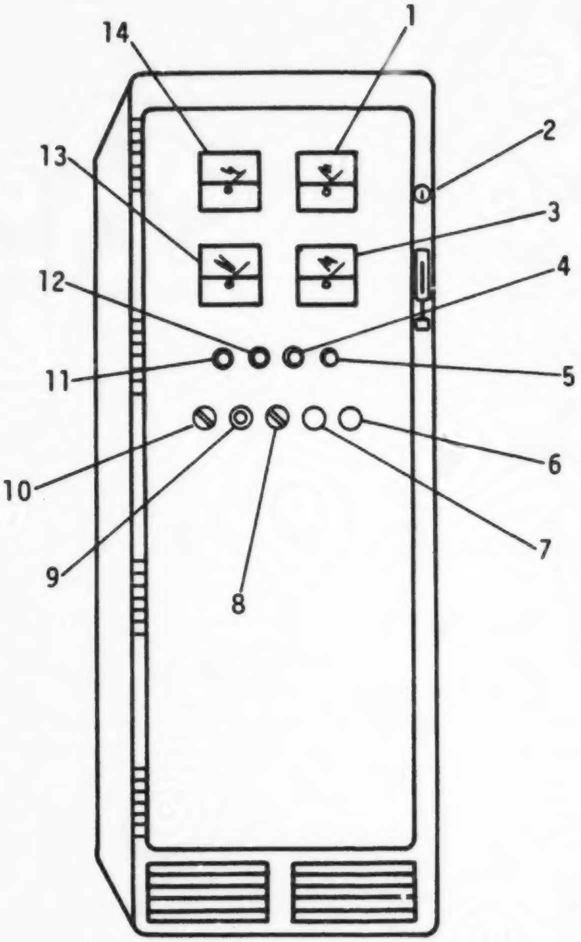
Numerous instruments may be used to monitor ESP performance and performance changes. These include primary and secondary voltage and current meters, spark meters, rapper monitors, transmissometers, hopper level indicators, and the usual temperature sensors. Other monitors may be used to determine gas conditions, such as oxygen levels; combustibles, CO, and CO_2 content; and SO_2 and NO_x emissions. Combined with process data, many of these instruments are important for determination of the day-to-day performance of the ESP. Some of the newer digital controls for ESP's will even allow these instruments to be linked together through the appropriate interface for automatic optimization of ESP performance. Each of the instruments is discussed briefly with regard to its usefulness in ESP performance evaluation.

3.2.1 Voltage and Current Meters

The readings from voltage and current meters indicate how the ESP is performing. The individual readings themselves are usually not important, but patterns created by these readings are. Because several different parameters influence the electrical readings of the ESP, it is usually the trends in the electrical readings that are used for diagnosis of operating problems.

Figure 3-3 illustrates a typical T-R set control panel used on modern ESP's. The four meters shown in the circuit are primary voltage, primary current, secondary voltage, and secondary current. Spark rate meters are also used but are not shown in this diagram. The terms "primary" and "secondary" meters are defined relative to the transformer primary (low-voltage) and secondary (high-voltage) windings.

Typical primary voltage and current meters are direct, in-line meters; i.e., the are tied directly to the increasing line voltage and current being applied to the transformer. Note: Because of its placement in the circuit,



1. KILOVOLTS
2. INTERLOCK
3. MILLIAMPS
4. ON
5. OFF
6. STOP
7. START
8. LOCAL-REMOTE
9. MANUAL ADJUST
10. AUTO-MANUAL
11. OPERATE
12. GROUND
13. AMPS (PRIMARY)
14. VOLTS (PRIMARY)

Figure 3-3. Typical T-R set control panel.

the voltage applied to the T-R primary will be less than the input line voltage (nominally 440 to 480 volts a.c., single-phase), and this should be reflected in the primary voltage meter. In some applications, however, the meter does not measure current flow or voltage directly, but it provides an indirect or proportional measurement through a transformer, and sometimes through an amplified circuit. In most circumstances, the primary meters are fairly accurate, whether they measure directly or indirectly.

The secondary meters are always an indirect method of measurement because of the operating voltages encountered on the secondary side of the transformer. The usual location of the secondary current meter is the ground return leg of the rectifier circuit, which may use a set of calibrated resistors or an amplifier circuit to determine the current flow. The secondary voltage is usually measured through a voltage divider resistance network off of the T-R output. Again, with calibrated resistors used to substantially reduce the current flow to the meter, the applied voltage can be measured indirectly or through an amplifier circuit. It should be noted that not all T-R's that display secondary voltage measure, even indirectly, the voltage on the secondary side of the transformer. Some circuits measure the primary voltage and then assume the secondary voltage to be proportional to the primary voltage. Review of the T-R schematics will usually indicate which system is used.

Another difference between the primary and secondary values is the level of voltage and current that is represented. Typically, the values reflected on the primary meters are the root mean square (RMS) values for current and voltage; however, the values displayed by the secondary meters are usually average rather than the RMS values. Thus, although changes in voltage and current that occur on the primary meter are usually reflected on the secondary meters, the relative magnitudes may differ because of the way the values are measured.

3.2.2 Spark Meter

The spark meter is usually a relatively simple circuit consisting of a calibrated meter placed on a resistor/capacitor circuit. The capacitor is charged by voltage pulses fed by the spark transient detector circuit. The larger the number of pulses fed to the capacitor, the higher is the voltage stored by the capacitor and discharged across the resistive circuit. Although this type of circuit also may be used in digital-type displays, more sophisticated circuitry is normally used to take advantage of the digital control technology. Because of its simplicity, this circuit works well if it is maintained. In many instances, however, this system has failed and the spark meter has become either inoperative or inaccurate. Where analog meters are provided, the spark rates usually can be determined by counting the number of sudden needle deflections over a period of time. This technique is useful for spark rates up to about 150 to 180 per minute. Above this rate sparks become difficult to count.

Some newer controls are equipped with spark indicators in the form of LED's (light-emitting diodes) rather than a spark rate meter. In many instances, these may also be used to indicate spark rate. Some systems may further divide sparks as light (or "split") sparks, moderate sparks, and heavy sparks (or arcs) for the convenience of setting up the controls. This feature may be useful in establishing maximum voltage/current levels for efficient operation. The spark measurement can be made on either the primary or secondary side of the transformer.

3.2.3 Rapper Monitors

Monitoring equipment for rapper control systems has been relatively limited, ranging from no instrumentation or indication of rapper operation to equipment that indicates intensity and operation cycle time. What is available depends greatly on the rapper type and equipment manufacturer.

The magnetic-impulse gravity-impact (MIGI) rapper can be equipped to indicate both the operation of the rappers and their relative intensity. The indicator may be a bulb or LED that is activated when the control circuit fires the signal to activate a rapper. More sophisticated rapper controls indicate which field or which rapper is being activated. In addition, the relative rapping intensity can be monitored by a current pulse sent to individual rappers, and a panel meter may be provided to indicate the percent of full current (maximum rapping intensity). Again, advances have allowed rapper instrumentation not only to control the length of time between rapping for each rapper, but to control individual rapper intensity. Most existing

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rapper controls, however, will only provide a uniform rapping intensity to the entire ESP or to individual fields.

The rapping intensity of mechanical, falling-hammer rappers cannot be varied easily; therefore, the length of the rapping cycle alone is controlled for each field. Timers are usually provided to indicate the dwell time between rapping cycles and the length of time that the rapper drives are activated. These two times can be varied to optimize rapping reentrainment.

Air-driven pneumatic rappers and electric vibrators usually have minimal instrumentation; however, they may be equipped with air pressure gauges and voltage meters, respectively, to provide an indication of rapping intensity. No monitors are used for direct measurement of rapping intensity within an operating ESP.

3.2.4 Transmissometers

Transmissometers can be useful both in determining performance levels and in optimizing ESP performance. A facility may have one or more monitors that indicate opacity from various ESP outlet ducts and from the stack itself. Opacity also may be measured on a real-time basis or over selectable averaging periods.

The opacity monitor simply compares the amount of light generated and transmitted by the instrument against the quantity received by the receiver. The difference, which is caused by absorption, reflection, refraction, and light scattering by the particles in the gas stream, is the opacity of the gas stream. Opacity is a function of particle size, concentration, and path length. Most opacity monitors are calibrated to display opacity at the stack outlet path length. Most of the opacity monitors being installed today are double-pass monitors; i.e., the light beam is passed through the gas stream and reflected back across to a transceiver. This arrangement is advantageous for several reasons: 1) automatic checking of the zero and span of the monitor is possible when the process is operational; 2) because the path length is longer, the monitor is more sensitive to slight variations in opacity; and 3) the electronics package is all located on one side of the stack as a transceiver. Although single-pass transmissiometers are available at a lower cost (and sensitivity), the double-pass monitor can meet the requirements for zero and span in Performance Specification 1, Appendix B, 40 CFR 60. Monitor siting requirements are also discussed in this specification.

For many sources, mass-opacity correlations can be developed to provide a relative indication of ESP performance. Although site-specific, these correlations can provide plant and agency personnel with an indication of relative performance levels for a given opacity and deterioration of performance that requires attention by plant personnel. In addition, the opacity monitor can be used to optimize spark rate, voltage/current levels, and rapping cycles, even though the conditions within the ESP are not static.

In some instances, it may take 6 months to optimize ESP rapping patterns and intensity to obtain the best electrical conditions and minimum reentrainment of particulate. One difficulty is the time required for the ESP to establish a new "equilibrium" dust layer on the plates. This is complicated by the ever-changing conditions within the ESP. In high-efficiency ESP's, however, reentrainment may account for 50 to 70 percent of the total outlet emissions, and optimization of the rapping pattern may prove beneficial. Transmissometer strip charts have been observed on well-operated and moderately sized ESP's that exhibit practically no rapping reentrainment spikes. Rapping reentrainment must be observed with the monitor operating in a real-time or nonintegrating mode (also called a "zero" integration time) such as the example shown in Figure 3-4. Rapping spikes tend to get smoothed out in integrated averages such as the 6-minute average commonly in use. The integrated average does provide a good indication of average opacity and emissions, however.

When parallel ESP's or chambers are used, an opacity monitor is often placed in each outlet duct, as well as on the stack, to measure the opacity of the combined emissions. Although the stack monitor is commonly used to indicate stack opacity (averaging opacities from different ducts can be difficult), the individual duct monitors can be useful in indicating the performance of each ESP or chamber and in troubleshooting. Although this option is often not required and it represents an additional expense, it can be very useful, particularly on relatively large ESP's.

New systems are available in which the opacity monitor data can be used as input for the T-R controller, for example, the new digital microprocessor

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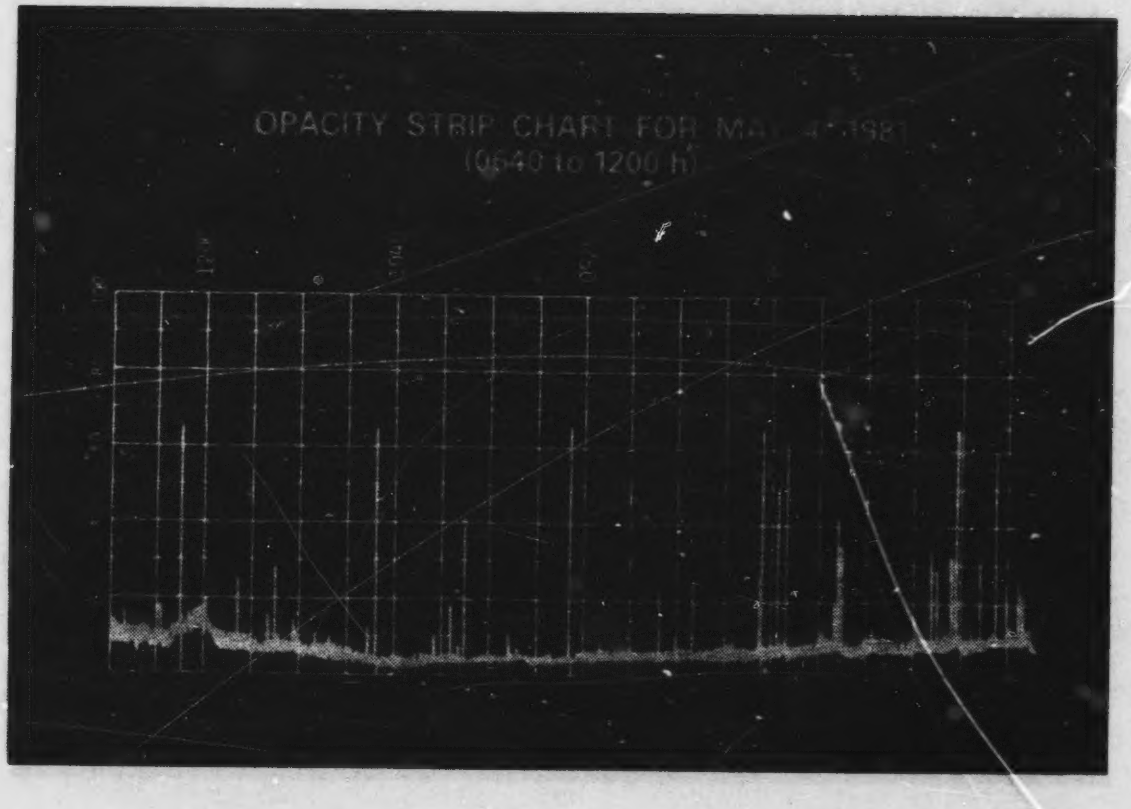

Figure 3-4. Example of rapping spikes on a transmissometer strip chart.

designs that are being sold or developed for new installations. Use of the opacity monitor data can decrease power input throughout the ESP to maintain some opacity level preselected by the source. If the opacity increases, the controller increases power input accordingly until the opacity limit, spark limit, current limit, or voltage limit is reached. This system (often sold as an energy saver) can save a substantial quantity of energy on large, high-efficiency ESP's, and at reduced gas loads. In many cases, reduction of ESP power does not significantly alter ESP performance because reentrainment and gas sneakage constitute the largest source of emissions, and additional power often does not reduce these emissions significantly. In some observed cases, reducing power by one-half did not change the performance. For units typically operated at 1000 to 1500 watts/1000 acfm, power levels of 500 to 750 watts/1000 acfm still provide acceptable collection efficiencies.

3.2.5 Hopper Level Indicators

Hopper level indicators could more accurately be called high hopper level alarms because they do not actually measure dust levels inside the hopper. Instead they send an alarm that the dust level within a hopper is higher than the level detector and that corrective action is necessary. The level detector should be placed high enough that "normal" dust levels will not continuously set off the alarm, but low enough to allow adequate response time to clear the hopper before the dust reaches the discharge frame and causes the T-R to trip or to misalign the ESP. Not all ESP's use or need hopper level indicators.

Two types of level indicators are commonly in use (although others are available). The older of the two is the capacitance probe, which is inserted into the hopper. As dust builds up around the probe, a change in the capacitance occurs and triggers an alarm. Although these systems are generally reliable, they can be subject to dust buildup and false alarms in some situations. A newer system, currently in vogue, is the nuclear or radioactive detector. These systems utilize a shielded Cesium radioisotope to generate a radioactive beam that is received by a detector on the opposite side of the hopper. Two of the advantages of this system are they do not include a probe that is subject to dust buildup and more than one hopper can be monitored by one radioactive source. The major drawback is that the plant personnel would be dealing with a low-level radioactive source and adequate safety precautions must be taken. These detectors are provided with safety interlocks to prevent exposure of plant personnel when maintenance is required.

Hopper level detectors should normally be located between one-half and two-thirds of the way up the side of the hopper. As long as hoppers are not used for storage, this should provide an adequate safety margin. It should be remembered that it takes much longer to fill the upper 2 feet of a pyramid hopper than the lower 2 feet.

Other indirect methods are available for determining whether the hopper is emptying properly. On vacuum discharge/conveying systems, experienced operators can usually tell where the hopper is plugged or if a "rat-hole" is formed by checking the time and vacuum drawn on each hopper as dust is removed. On systems that use a screw conveying system, the current drawn by the conveyor motor can serve as an indicator of dust removal. Another simple method for determining hopper pluggage is through a thermometer located approximately two-thirds of the way up on the hopper. If dust covers the probe because of hopper buildup, the temperature will begin to drop, which signals the need for plant personnel to take corrective action.

3.2.6 Miscellaneous Equipment

CO and Combustibles Analyzers--

Some source categories, most notably portland cement plants, use CO or combustible analyzers as a safety device to detect high levels and to prevent high levels that form a combustible mixture from entering an energized ESP where a spark could ignite or detonate the mixture and cause substantial damage to the ESP. Although this is usually related to process malfunctions, the damage to the ESP can seriously hinder performance and limit production rates in the future.

Each of several instruments and measurement methods on the market today has its advantages and limitations. All have the common function of indicating an undesirable condition, sending an alarm, and possibly automatically deenergizing the ESP until the danger has passed. Many sources monitor CO where excursions are expected, because CO in combination with oxygen at the right concentration can form a combustible mixture. Other compounds [e.g., methane (CH_4) and hydrogen (H_2)] may be more important in the prevention of explosions, however. These compounds increase the range of explosive mixtures by changing the upper and lower limits of the CO-air mixture and enhance the possibility of explosion within the ESP. Most CO monitors do not monitor combustibles and are relatively insensitive to them. Thus, an explosive mixture can exist within an ESP without the limiting CO value that sets off an alarm ever being reached.

Two other problems may occur with regard to monitoring CO and combustibles. First, monitors that rely on catalytic combustion to determine combustibles must have sufficient available oxygen to complete the reaction to form CO_2 and water. This level is generally greater than 3 percent O_2 in the flue gas. The second and perhaps more serious problem is the monitor response time. Monitor response times on the order of 45 seconds to 2 minutes are not unusual. In cases where the CO or combustible spike is detected because of some process upset, the danger often has passed by the time the monitor responds. Monitors and special probes are available that have much shorter response times (2 to 5 seconds), but these tend to be quite expensive and have a relatively short life. The cost may be more than offset, however, by the cost of having to repair or rebuild an ESP and other components as a result of an explosion.

3.3 PERFORMANCE TESTS AND PARAMETER MONITORING

The operating characteristics of an ESP are such that several concepts are useful in a performance evaluation. These include parameter monitoring and baseline assessments. These concepts, which will be defined further, form the basis for good recordkeeping and a preventive maintenance program aimed at achieving continuous compliance of the controlled source.

From a regulatory standpoint, compliance is determined by a performance test involving the use of a Reference Method, such as Method 5 or 17. In between these periodic performance tests, compliance also may be determined by the use of opacity observations according to the requirements of Reference Method 9. Because these emission tests represent only a small segment of time in the daily operation of the process and ESP, the performance during the emissions test may not be representative of characteristic daily operations. Nevertheless, these emissions tests do afford the opportunity to

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document process and ESP operating conditions that influence performance. By providing a known level of performance, these values serve as a benchmark or baseline condition for future comparisons with data collected during routine parameter monitoring and recordkeeping or as part of diagnostic troubleshooting. The establishment of these baseline conditions makes it possible for a number of parameters to be compared to determine their effect on performance. This comparison is particularly useful for ESP's because many parameters can affect performance to varying degrees. It is the magnitude of these changes that is important. Baseline conditions may include both air-load and gas-load tests in addition to the data obtained during emission testing.

Parameter monitoring, an extension of baselining the ESP and process equipment, forms the basis of diagnostic recordkeeping and preventive maintenance. Several key parameters are usually monitored to track ESP performance. Generally, parameter monitoring includes both process and ESP data because both are important to ESP performance. An analysis of these key parameters and a comparison with baseline values can define many performance problems, indicate the need for maintenance, and define operating trends within the ESP. For example, at a utility burning several types of coal, performance may deteriorate or be enhanced by one type of coal or another. Rather than accepting these performance changes as part of the daily variation, these fuel-related variations may be avoided by exercising special operating precautions or perhaps eliminating a certain coal type. Determining the cause of variations can often be more beneficial than merely accepting the problem at face value. Parameter monitoring is most useful in moderate-sized to moderately large ESP's. Undersized or oversized ESP's tend to be less sensitive to changes in the key operating parameters in the efficiency ranges of greatest interest.

3.3.1 Performance Tests

The performance test often is the deciding factor for the acceptance of a new ESP, and many agencies require periodic testing (anywhere from quarterly to once every 3 to 5 years). The initial performance test certifies that the ESP is designed to be capable of meeting the specifications. These initial performance tests may also include tests with sections of the ESP out of service to meet special requirements of the permit, specifications, or

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regulatory requirements. The initial performance tests may also include inlet tests to establish mass loading, collection efficiency, and, in some cases, inlet particle size characteristics.

Testing requirements vary from site to site, and they should be established in a testing protocol; however, one of two test methods is generally specified for determining particulate emission rates. These are EPA Reference Methods 5 and 17 (40 CFR 60, Appendix A). In both methods, a sample is removed isokinetically from various sample locations to prevent the sample results from being biased. The main difference between the two methods is the location of the filter in the sample train. The Method 5 sample train uses an external filter held in a temperature-controlled hot box. The sample passes through the heated sample probe and filter into the impinger train for removal of condensible materials (water, condensible organics). The particulate emission rate usually will be determined from the probe and filter catch alone (front-half catch); however, some regulatory limitations specify the use of both front- and back-half catches (which include the impinger catch minus water). In most cases, the specified temperature is 250° ± 25°F for the filter of a Method 5 sample train, but special conditions allow a temperature up to 320° ± 25°F.

Method 17, on the other hand, uses an in-stack filter to capture particulate. After the filter temperature has been allowed to equilibrate to stack conditions, the sample is drawn through the nozzle and into the filter. The sample is then passed through a set of impingers to remove condensibles from the gas stream.

The two methods often do not provide equivalent results, even when the flue gas temperature is the same as the hot box temperature. First, Method 5 defines particulate as the material that is captured on a filter at the hot box temperature (nominally 250°F), although the temperature of the gas stream passing through the filter may be substantially different than the hot box temperature. This is important because many "particulates" are temperature-dependent, i.e., they exist below a certain temperature, but they may remain in a gaseous form above a given temperature. Theoretically, particulate matter is referenced to a particular temperature. Second, some losses are normally associated with recovering the particulate from the in-stack filter of

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the Method 17 sample train, and a correction must be applied (e.g., 0.04 gr/scf for kraft recovery boilers). Lastly, because Method 17 is referenced to the stack temperature, the definition of what constitutes "particulate" may be different. Method 17 is usually reserved for particulates or processes that do not involve a particular temperature dependency. When this is the case, the results of both methods are usually in relatively close agreement.

There has been widespread discussion as to which method should be used when a choice is allowed. Each method can be manipulated to provide the most favorable emission rate. Method 17 may more accurately reflect the conditions the ESP may encounter; however, Method 5 attempts to standardize the operating temperature so that differences in temperature and temperature dependency are minimized.

In addition to overall particulate emission rates, some regulations limit the emission of fine particles. Such limits require particle size analysis, either by microscopic methods or by the use of cascade impactors. Cascade impactors are placed in the stack in a manner similar to the placement of an in-stack filter. An impactor consists of a series of perforated plates and target or impact stages in which an impact medium (grease or fiberglass substrate) is used. As the gas and particulates pass through the impactor, they are accelerated to higher velocities. The particulate matter has difficulty staying with the flow streamlines and its inertia carries it to impact the target stage. Each stage is sized to capture a predetermined particle size range at a given flow rate. Calibration curves and corrections to the particle size ranges are provided by the equipment manufacturers.

There are two problems related to the use of cascade impactors. First, the gas stream must be sampled isokinetically to avoid skewing the particle size distribution. Under-isokinetic sampling (at a probe velocity less than that of the stack or duct) usually results in a distribution skewed toward large particles, whereas over-isokinetic sampling favors smaller particulate. Also, the particle size distribution may have little bearing on the Method 5 results because of the temperature-dependency of the particulate. Second, the isokinetic sampling requirement means that the sample must be drawn at a given flow rate and the flow rate cannot be varied to maintain calibration of the impactor. Varying the flow rate would vary the particle size distribution each stage would capture. This usually results in single-point sampling being used, with all the limitations associated with the representativeness of the sample. In some cases, multipoint sampling may be carried out, but careful planning and, for multiple impactors, good flow distribution are necessary.

Opacity is usually monitored during the performance test with an opacity monitor and/or by Method 9 observations. Some efforts have been made to correlate mass and opacity to provide a performance indicator by conducting multiple tests while altering ESP performance (by turning power down or off on certain T-R's) to generate upscale data points. Opacity readings taken during each test run (either monitor data or Method 9 observations) are then averaged.

Several sources have done some work to establish mass/opacity correlations, most notably in utility applications, which prompt the following general observations. First, mass/opacity correlations appear to depend on a number of industry- and site-specific factors, including size distribution, stack path length, and process-related factors. Second, at a number of sources, consistent relationships have been found over a period of time (regardless of process load) provided neither the process nor the ESP is experiencing severe malfunctions. The process operation seems to be the controlling factor in most cases. For example, much of the data for utility applications suggests that the mass/opacity relationship is relatively constant for a given source; however, a burner problem that produces high carbon content in the flash can shift the mass/opacity. A similar shift occurs on kraft recovery boilers and some cement kilns. In general, when a condensible particulate is present, the mass/opacity correlation may not be reliable. Third, opacity monitor data tend to produce "tighter" or better correlations than Method 9 when 95 percent confidence intervals are calculated for the correlation. Observer biasing can result from changing background conditions or from "between-observer" differences; whereas a properly maintained monitor usually is not subject to biasing problems. Lastly, confidence intervals tend to become very large at the extreme ends of the curves when mass and/or opacity is either very low or high. At the low mass/opacity end of the curve, the relative errors, particularly in test methods, can become substantial. Although the mass loading is very high at the upper end, little change may occur in opacity. In fact, so much of the ESP may be deenergized that it may not behave as it would if it were running normally; it may behave as though it were designed differently and significantly undersized. In the opacity ranges of interest to most agencies and sources, however, the confidence intervals can be quite tight. This opacity correlation, although not usually used for compliance determinations, can be useful in evaluating operation and maintenance, which was the original intent behind the requirement for continuous emission monitors.

3.3.2 Baseline Assessment

Although baseline assessment actually should begin before a new ESP is operated, the establishment of baseline conditions for an ESP during a performance test provides a basis for comparison in future evaluations of the ESP. The baseline serves as a reference point, and the types and magnitude of shifts from baseline conditions are important in evaluating ESP performance.

For a new ESP, baselining includes an air-load test prior to operation while the plates and wires are in a clean condition. After work has been completed and the final physical checks have been made, the ESP is closed and prepared for energization. An air-load test should be run on each field to generate a V-I curve. The values for the voltage/current relationship should be similar for fields of the same design. Items such as T-R capacity, square feet/T-R (sectionalization), and wire design (barbed vs. smooth) will influence the shape of the curves, as will any physical defect in construction. This test serves as a check on the electrical capacity of the unit as well as a check on the construction of the ESP while it is still in a clean condition and problems can be corrected. When the unit has been started up and operated, the air-load curves will be different because of the residual dust on the plates.

Air-load tests prior to a performance test (in case of a shutdown prior to the test) will also confirm the electrical performance of the ESP. Gas-load tests also can be performed before and during a performance test. The gas-load test is performed under actual gas flow and particulate conditions to generate a V-I curve for each field. Several items should be noted. The shape and length of the curves will vary somewhat because the process and ESP form a dynamic system. The absolute values of voltage and current are not as important as the trends observed within the ESP; these trends help in the evaluation of the ESP's operating condition during the performance tests. Gas-load tests can be performed before, during, and after a performance test, with one cautionary note. Because conducting a gas-load test often upsets ESP performance for 5 to 20 minutes, some time should be allowed for the ESP to stabilize before testing (particularly between runs of the performance test).

Most of the effort expended during the collection of baseline performance readings is in the area of process and ESP operating data. Process data may include production weight, raw material and product feed characteristics, operating temperatures and pressures, combustion air settings, and cycle times (for cyclic processes). The ESP data will include electrical readings (usually several readings per run), temperature, gas flow rate, opacity, rapping cycle, and excess air levels.

Although accurate predictions cannot be made of the exact effect a change in most of these parameters will have on performance, a qualitative evaluation can often be made when values deviate from baseline conditions, and these deviation values are useful in parameter monitoring.

3.3.3 Parameter Monitoring

Parameter monitoring usually plays a key role in an overall operation and maintenance plan, particularly one that stresses preventive maintenance. Such monitoring also forms the basis for a recordkeeping program that places emphasis on diagnostics. Typically, daily operating data are reduced to the data on a few key parameters that are monitored. Acceptable ranges may be established for various parameters (by use of baseline test data) that require further data analysis or perhaps some other action if the values fall outside a given range. Care must be taken not to rely on just one parameter as an indicator, as other factors, both design- and operation-related, usually must be considered. Typical parameters that can be monitored include opacity, corona power input, gas flow rate through the ESP, gas temperature

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and oxygen content, process operating rates, and conditioning systems (if used).

Many sources use opacity levels as the first indicator of performance changes. In general, opacity is a good indicator and tool for this purpose. If used in conjunction with mass/opacity correlations, it can help in the scheduling of maintenance and in the reduction or optimization of ESP power input. It is not wise to rely on opacity data alone, however, as such reliance can cause one to overlook problems that can affect long-term performance (e.g., hopper pluggage may not significantly increase opacity at reduced load, but it may misalign the affected fields and reduce their performance at full load or in other difficult operating situations).

Another useful parameter is the corona power input to the ESP, which can be thought of as a measure of the work done to remove the particulate. Corona power input can be obtained by multiplying the voltage and current values of either the primary or secondary side of the transformer. As noted earlier, the apparent power input on the primary and secondary side will differ because of circuitry and the metering of these values. Values from the secondary meters are preferred. As a general rule, performance improves as the total power input increases. This is normally the case when resistivity is normal to moderately high, assuming most other factors are "normal" and components are in a state of good repair. One should not rely solely on power input, however. The pattern or trends in power input throughout the ESP are important in a performance evaluation. Also in some cases, although the apparent power input is high, the performance is poor. For example, when dust resistivity is low or very high or when spark rates are very high, corrective measures will usually lower power input, but will also substantially improve performance.

Some ESP's are relatively insensitive to power input changes. This condition is usually limited to high-efficiency ESP's that are generously sized and sectionalized. The normal power input of some of these ESP's may be reduced by one-half to two-thirds without causing any substantial change in performance. The emissions from the ESP's are caused primarily by rapping reentrainment and gas sneakage, both of which are relatively unaffected by

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the level of power input. In this case, power reduction for energy conservation is probably a useful option.

Varying corona power input affects power density (watts/square foot of plate area). This may be tracked two ways: 1) by obtaining an overall value for the ESP, or 2) by checking the power density in each field from inlet to outlet of the ESP. Power density should increase from inlet to outlet as the particulate matter is removed from the gas stream (the maximum value is usually less than 4 watts/ft^2). Power density accounts for the differences or normalizes the values for power input in each field that are caused by different field size. Most normally operating ESP's will show an overall power density of 1 to 2 watts/ft^2; values of 0.10 to 0.50 watt/ft^2 are more common for high-resistivity dusts.

The gas volume passing through the ESP is important to the actual SCA, the superficial velocity, and the treatment time. The temperature of the gas stream, the excess-air values (for combustion sources), and the production rate all influence the gas volume entering the ESP. If gas volume is known or estimated, the specific corona power (watts/1000 acfm) can be calculated. This value tends to account for changes in performance due to different loads and power input because removal efficiency generally increases as the specific corona power increases. The same cautionary remarks that apply to overall power input also apply to specific corona power. The values obtained for specific corona power input may be misleading if other factors are not considered.

3.4 RECORDKEEPING PRACTICES AND PROCEDURES

Recordkeeping practices for ESP's range from none to maintaining extensive logs of operating data and maintenance activities and storing them on computer disks. The data obtained by parameter monitoring form a basis for recordkeeping, as this type of data usually indicates ESP performance. Recordkeeping allows plant personnel to track ESP performance, evaluate trends, identify potential problem areas, and arrive at appropriate solutions. The magnitude of the recordkeeping activity will depend on a combination of factors, such as personnel availability, size of the ESP, and the level of maintenance required. For moderately sized, well-designed, and well-operated

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ESP's, maintaining both daily operating records and maintenance records should not be too cumbersome; however, only records of key operating parameters should be maintained to avoid accumulating a mountain of unnecessary information.

Recordkeeping practices can be separated into two major areas, operating records and maintenance records, each of which can be further divided into subcategories. When setting up a recordkeeping program, one should give attention to both areas because they are required to provide a complete operating history of the ESP. This operating history is useful in an evaluation of future performance, maintenance trends, and operating characteristics that may increase the life of the unit and minimize emissions. Even though recordkeeping programs are site-specific, they should be set up to provide diagnostic and troubleshooting information, rather than merely for the sake of recordkeeping. This approach makes the effort both worthwhile and cost-effective.

Other supplementary records that should be maintained as part of the permanent file for operation and maintenance include data from air-load tests conducted on the unit, all baseline assessments that include both process and ESP operating data, and data from emission tests. A spare parts inventory listing should also be maintained, with periodic updates so that parts may be obtained and installed in a timely manner.

3.4.1 Operating Records

As mentioned previously, the specifics on what parameters will be monitored and recorded and at what frequency will be largely site-specific. Nonetheless, the factors that are generally important in parameter monitoring will also be the ones recorded as part of a recordkeeping program. Such data would typically include the process operating rate, T-R set readings, opacity monitor readings, and perhaps some reduced data on power input, power density, or specific corona power. These data probably should be gathered at least once per shift. The greater the frequency of data gathering, the more sensitive the operators will be to process or ESP operational problems, but the amount of data to manipulate also increases. The optimal frequency may be every 4 hours (twice per shift). If sudden and dramatic changes in performance occur, if the source is highly variable, or if the ESP operation is extremely sensitive, shorter monitoring intervals are required. On generously sized ESP's, intervals of once or twice a day may be adequate.

In addition to the numerical values of the operating parameters, a check list should be included to confirm operation of rappers, hopper systems (or other dust-removal systems), the absence of inleakage, and the other general physical considerations that can adversely influence ESP performance.

3.4.2 Maintenance Records

Maintenance records provide an operating history of an ESP. They can indicate what has failed, where, and how often; what kind of problems are typical; and what has been done about them. These records can be used in conjunction with a spare parts inventory to maintain and update a current list of available parts and the costs of these parts.

The work order system provides one of the better ways to keep maintenance records. When properly designed and used, this system can provide information on the suspected problem, the problem actually found, the corrective action taken, time and parts required, and any additional pertinent information. The system may involve the use of triplicate carbon forms or it may be computerized. As long as a centralized system is provided for each maintenance activity, the work order approach usually works out well.

Another approach is to use a log book in which a summary of maintenance activities is recorded. Although not as flexible as a work order system (e.g., copies of individual work orders can be sent to various appropriate departments), it does provide a centralized record and is probably better suited for the small ESP facility.

In addition to these centralized records, a record should be maintained of all periodic checks or inspections. These should include the periodic weekly, monthly, semiannual, and annual checks of the ESP that make up part of a preventive maintenance program. Specific maintenance items identified by these periodic inspections should be included in the recordkeeping process. The items to be checked are discussed in more details in Section 6.

3.4.3 Retrieval of Records

A computerized storage and retrieval system is ideal for recordkeeping. A computer can manipulate and retrieve data in a variety of forms (depending upon the software) and also may be useful in identifying trends. A computerized system is not for everyone, however. The larger the data set to be handled, the more likely it is that a computer can help to analyze and sort data. For a small source with an ESP that presents few problems and that has a manageable set of operating parameters to be monitored, a computer system could be very wasteful (unless computing capability is already available). Also, it is sometimes easier to pull the pages from a file manually, do a little arithmetic, and come up with the answer than to find the appropriate disks and files, load the software, and execute the program to display "the answer."

Retention time is also a site-specific variable. If records are maintained only to meet a regulatory requirement and are not used or evaluated, they can probably be disposed of at the end of the statuatory limitation (typically 2 years). It can be argued that these records should not be destroyed because if the ESP (or process) should fail prematurely, the data preserved in the records could be used as an example of what not to do. On some ESP's in service today, records going back 10 to 12 years have been kept to track the performance, cost, and system response to various situations and the most effective ways to accomplish things. These records serve as a learning tool to optimize performance and minimize emissions, which is the underlying purpose of recordkeeping. Some of these records may very well be kept throughout the life of the equipment. After several years, however, summaries of operation and maintenance activities are more desirable than the actual records themselves. These can be created concurrently with the daily operating and maintenance records for future use. If needed, actual data can then be retrieved for further evaluation.

SECTION 4

PERFORMANCE EVALUATION, PROBLEM DIAGNOSIS, AND PROBLEM SOLUTIONS

Although ESP performance is complex and sensitive to a number of variables associated with the process, it can usually be related to its internal electrical characteristics. These electrical characteristics, which are usually monitored by the T-R set control cabinet voltage and current readings, serve as the basis for performance evaluation and troubleshooting of the ESP. Thus, it is important for personnel responsible for evaluating or maintaining ESP performance to maintain good records and to understand the significance of these recorded values. Proper evaluation of the data may have a significant effect on both the short- and long-term performance of the ESP as well as maintenance requirements.

Difficulties often arise in the interpretation of the data because plant personnel do not realize what is "normal" in their ESP or because they do not understand the importance of these values to ESP performance. Establishing what is "normal, good performance" through good recordkeeping practices helps to provide a data base against which responsible personnel may compare daily operating values. This "baseline" condition serves as a benchmark against which to compare changes in operating conditions of either the process or ESP and to help decide what effect, if any, these changes have had on ESP performance. Although an emission test is the ultimate indicator of compliance with emission limitations, some method should be available for agency personnel or plant personnel to evaluate the nature and magnitude of any problem(s) in an operating ESP without resorting to a stack test every time there is a suspected problem.

A further complication in the evaluation of ESP performance is that a change in operating characteristics may be a symptom of not just one problem, but several unrelated problems. Enough data must be gathered for the symptoms to reduce the potential problems to one or two possibilities. In addition, synergistic or "chain-reaction" effects often result in one problem or failure leading to another, which in turn leads to a third failure and so on. This sometimes makes it difficult to decide what the initial failure was and what corrective action is needed.

This section discusses the uses of available data in evaluating ESP performance and diagnosing the more common ESP problems and the corrective actions available for both long- and short-term improvement of performance. Much of the long-term improvement relies on good recordkeeping practices (both operation and maintenance records) as discussed in Section 3.4.

4.1 PERFORMANCE EVALUATION

Most of the performance changes that occur in ESP's are reflected in the electrical characteristics that are monitored and controlled by the T-R set control cabinets. These changes may be caused by a failure of some internal ESP component or by a change in process operation. Because some changes are very subtle (e.g., a change in gas temperature or excess air level, a change in primary/secondary air ratios in a recovery boiler, or a shift in the feed material characteristics), monitoring and recording the pertinent operating parameters are important aspects of a performance evaluation.

At some sites all important parameters may not be monitored, and some that are monitored and recorded may be of little use in a performance evaluation. Although a site-specific evaluation will depend on the process involved and the instrumentation available, most ESP's should be equipped with at least primary voltage, primary current, and secondary (or precipitator) current monitoring equipment. Newer designs will incorporate a secondary voltage monitor and may forego altogether the monitoring of primary voltage and current. These meters will be used to assess ESP performance and to diagnose operating problems.

Obtaining and maintaining these data for diagnostic purposes can become quite cumbersome, particularly with some of the newer ESP designs that are generously sized and highly sectionalized. Plant personnel may find it relatively simple to keep track of three, four, or five T-R's and some key process operating parameters on a day-to-day basis; but maintaining records of readings on anywhere from 10 to 200 T-R's becomes a very difficult, if not completely unmanageable, task. Data acquisition and retrieval systems help in these situations, but detailed analysis may also be necessary. Thus, in any performance monitoring or audit program, one must first decide what will be monitored and recorded and in what form. Again, this will depend on site-specific equipment and design factors.

Two considerations are necessary in any performance audit or evaluation of an operating ESP. The first concerns the design factors that are built into the ESP. These include such parameters as the specific collection area (SCA), number of fields, number of T-R's, electrical sectionalization, T-R set capacity, design superficial velocity and treatment time, aspect ratio, and particulate characteristics. This background information permits the auditor or evaluator to determine what the ESP was designed to do and whether operating parameters have changed significantly from design. The second consideration concerns the use of baseline data to establish normal or good operating conditions. These baseline data could consist of values recorded during an emissions test or could be a compilation of operating records to establish normal operating conditions.

No single parameter should be used to evaluate performance; a combination of factors is more likely to be reliable. Although some parameters are more important and have greater effect than others, it is usually the combination of these parameters that determines performance of the ESP.

Depending on the situation, at least one person should be responsible for overseeing the operation of the ESP's, for reducing the data to a usable form, performing the evaluations, identifying potential problems, and helping to schedule maintenance. Other personnel may gather data, but one person should understand the significance of the gathered data.

How often and how much data should be gathered is a site-specific decision that will depend on equipment size, design factors, and personnel availability. The purpose of these data is to provide sufficient information for an effective evaluation of performance. Extraneous data of limited value should not be collected unless a specific problem is expected or encountered. When a program of recordkeeping is just being established, however, it is

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better to err on the side of having more data than needed at the beginning. Unnecessary duplication of recordkeeping should be avoided. This is particularly true of process information involving final quality data that may already be retained by plant personnel. These process records should be available to the personnel responsible for monitoring ESP performance if more detailed data are needed beyond that recorded for the ESP performance evaluation.

4.1.1 Data Collection and Compilation

Recording T-R Set Data--

The primary indicators of performance are the electrical operating conditions monitored at the T-R control cabinet. These conditions are reflected in the primary voltage, primary current, secondary voltage, and secondary current. Even if all these are not monitored (on older ESP's secondary voltage often is not monitored, and on some newer ones primary voltage and current are not monitored), the values provided should be recorded.

The level of effort required for this task depends on the size of the ESP and on the number of parameters monitored. For relatively small ESP's equipped with two to five T-R sets, very little time is required to record the data. The time required for the larger and more sectionalized ESP's, however, can be substantial.

The T-R data may be recorded in tabular form with the appropriate data for each T-R set. Again, for ESP's with a small number of T-R sets, this form makes it relatively easy to assemble the data and to track inlet, center, and outlet field performance. Plant personnel will be looking for certain patterns that are indicators of ESP performance levels. For larger ESP's the tabular form speeds up data gathering, but it does not immediately provide a visual pattern of ESP performance. For example, in most well-designed, operated, and maintained ESP's, the current tends to increase from the inlet field to the outlet field. In a large ESP with 10 or more fields, it may be difficult to visualize this effect if the physical placement of the T-R control cabinets or the arrangement of the T-R numbering system do not permit recording the data from inlet to outlet.

When the tabular form is less than satisfactory, a more graphical approach can be taken. Several graphical approaches are available for

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obtaining these data in a more useful form. The simplest of these is to draw the ESP plot plan with the relative position of the plate area of each T-R blocked out and to place the electrical data for each T-R in the appropriate box (see Figure 4-1). This is useful for evaluating the performance of large ESP's and those having fields of different dimensions. When the data gathering is completed, a look at the values for each field will quickly indicate if the desired pattern is there. This graphical representation will also show how many fields are out of service and how severe the problem may be (see Figure 4-2). Total plate area of out-service for the entire ESP can then be observed over a number of days, as shown in Figure 4-3.

Another graphical method is to plot the electrical data on a graph for each field from inlet to outlet (one for each chamber or grouping of T-R's, if necessary). This also allows a visual evaluation of the data for characteristic patterns (see Figure 4-4). Usually, all electrical parameters do not have to be plotted, as secondary current and voltage are good first indicators. For ESP's with different plate areas per T-R, it may be useful to normalize the data by dividing the values by the square feet of plate for each T-R. The resulting current densities should reflect the desired pattern of increasing current from inlet to outlet. (Note: In some cases, the same ESP will have T-R sets with energized fields varying from 1.5 to 12 feet in depth. These ESP's may have been designed this way, or they may have changed over time. In either case, the non-normalized values may reveal strange electrical characteristics.)

Although both of these graphical techniques are good for collecting and visualizing electrical characteristics, they have the shortcoming of only depicting ESP performance during the period when the values are taken; they cannot reflect trends in performance over time.

Another graphical method that can be used to evaluate long-term changes in ESP performance involves plotting the values of interest on a time chart (time on x-axis, voltage/current on y-axis). Two examples of this technique are shown in Figure 4-5. This chart allows maintenance personnel to note any changes that are occurring and the rate of change. Although this system of data compilation provides an excellent visual analysis of operating trends, it does not provide a good means of comparing voltages and currents directly

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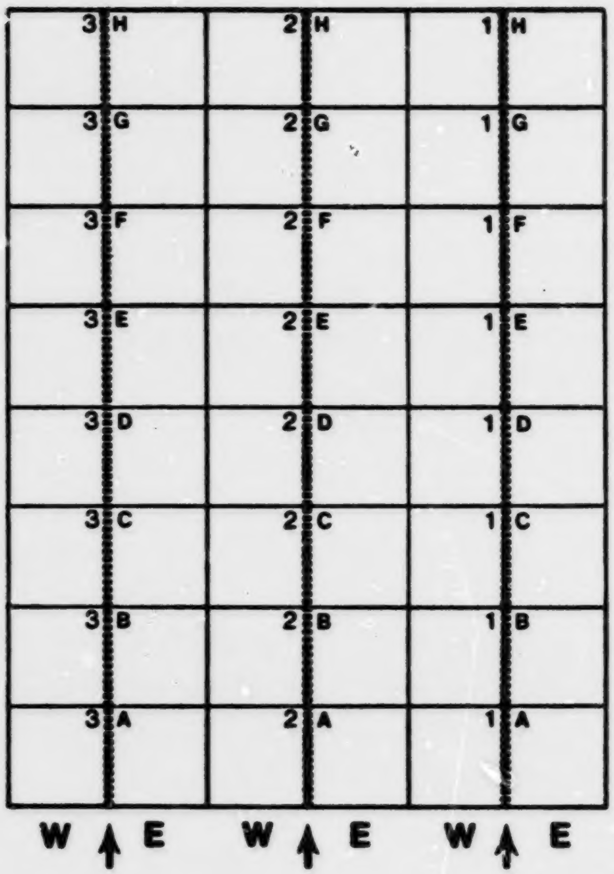
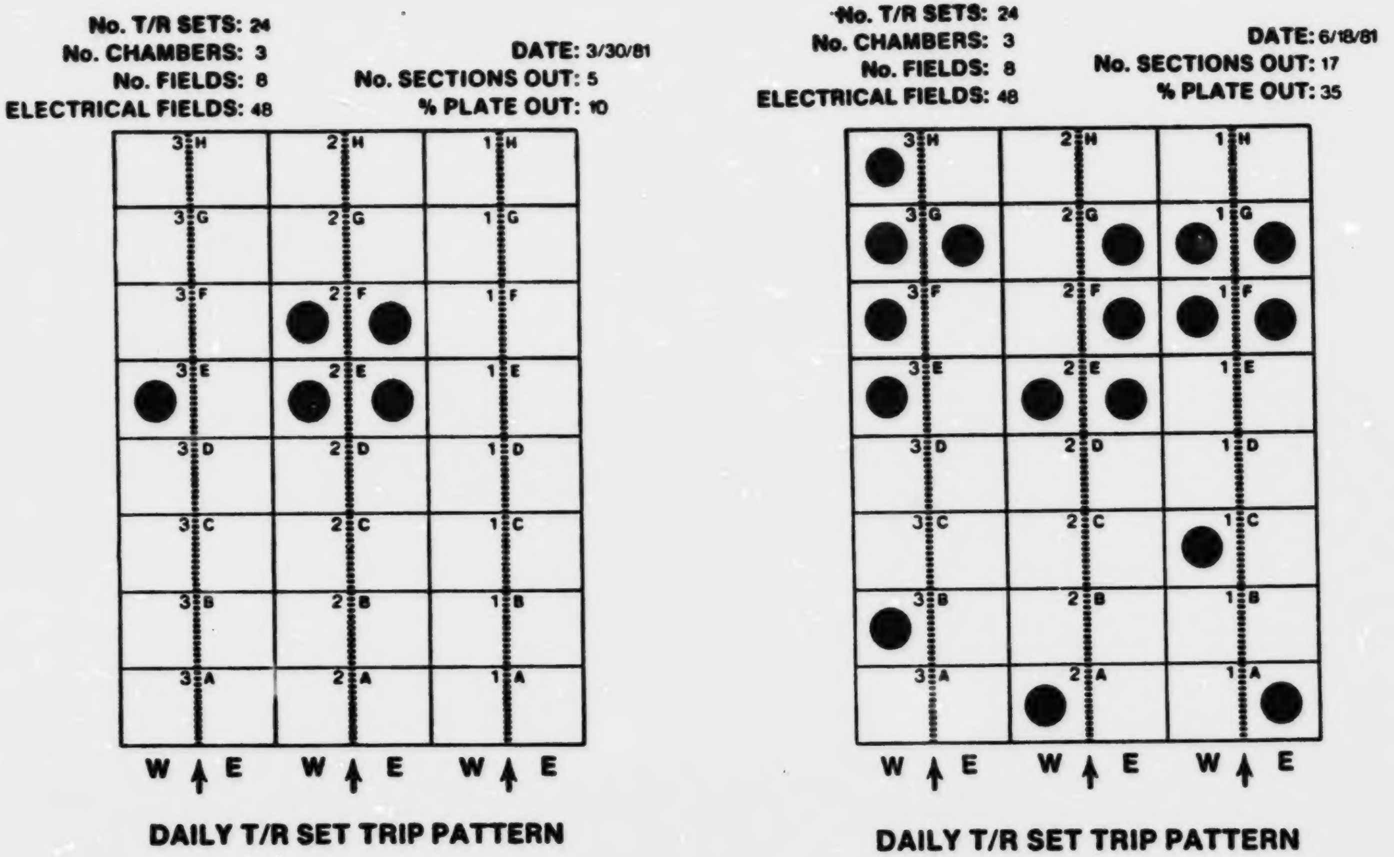


Figure 4-1. Typical plot plan layout for recording ESP operating data.



No. T/R SETS: 24
No. CHAMBERS: 3
No. FIELDS: 8
ELECTRICAL FIELDS: 48
DATE: 3/30/81
No. SECTIONS OUT: 5
% PLATE OUT: 10

DAILY T/R SET TRIP PATTERN

No. T/R SETS: 24
No. CHAMBERS: 3
No. FIELDS: 8
ELECTRICAL FIELDS: 48
DATE: 6/18/81
No. SECTIONS OUT: 17
% PLATE OUT: 35

DAILY T/R SET TRIP PATTERN

Figure 4-2. Comparison of T-R set trip patterns for two different days.

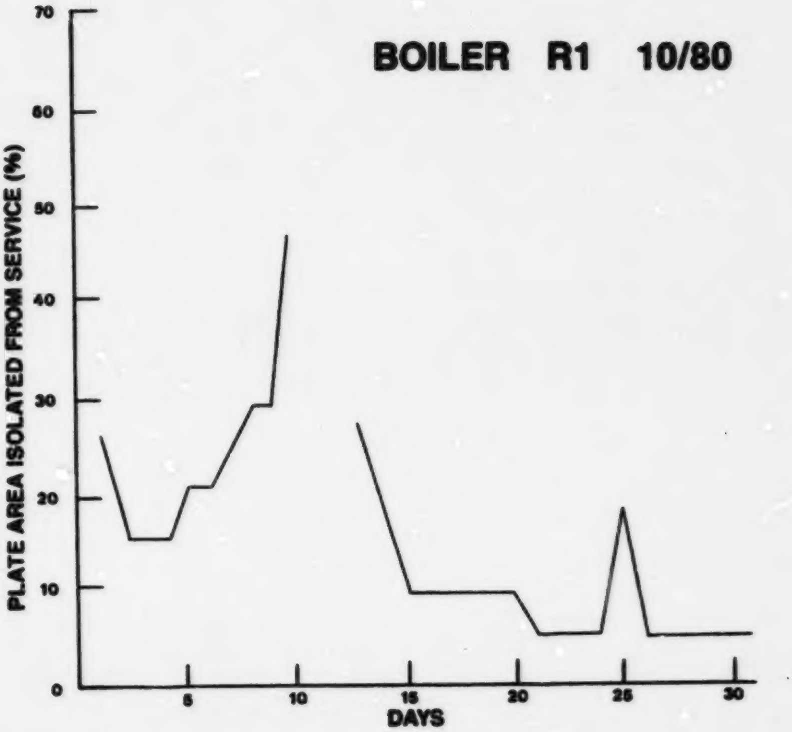


Figure 4-3. Graphical display of plate area of service over a 30-day period.

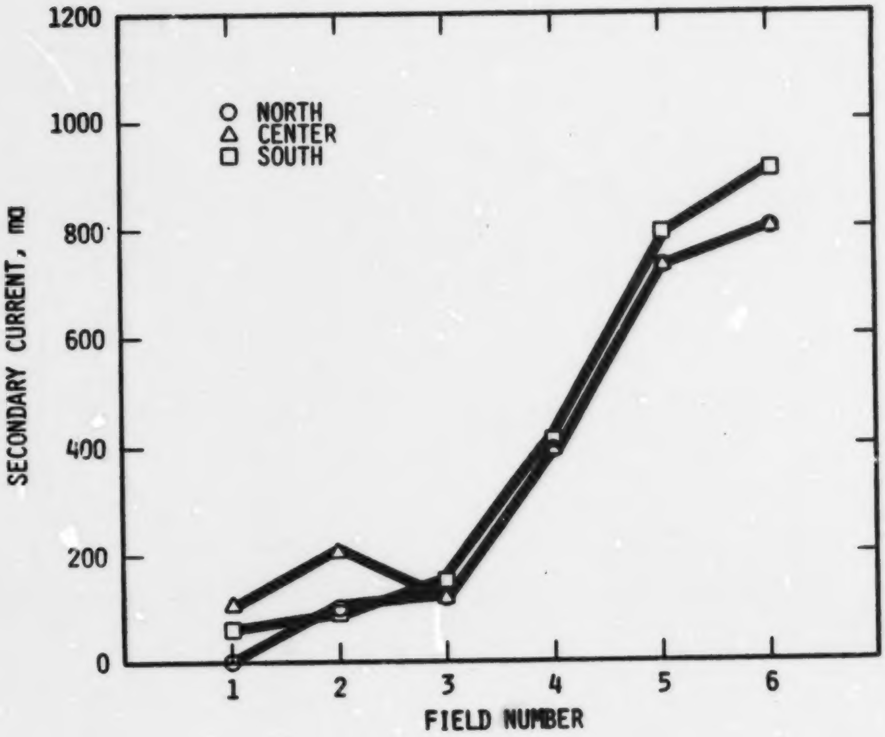


Figure 4-4. Graphical plot of secondary current vs. field for a 3-chamber ESP.

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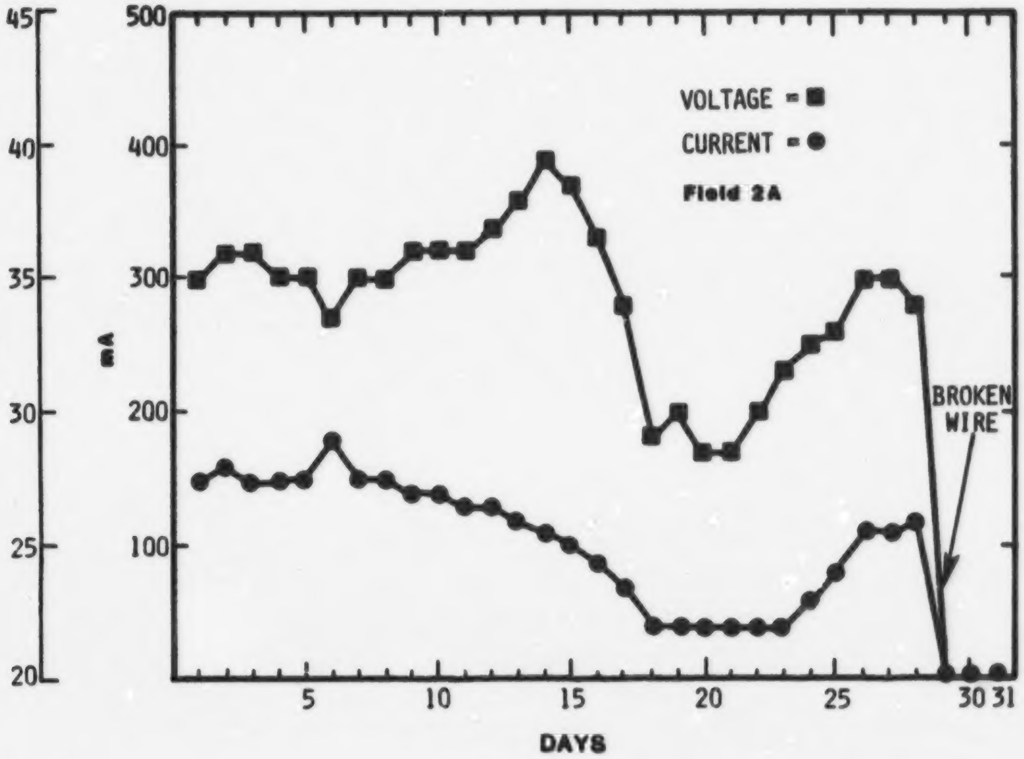

Figure 4-5a. Example of graphical displays of secondary current and voltage vs. day of operation.

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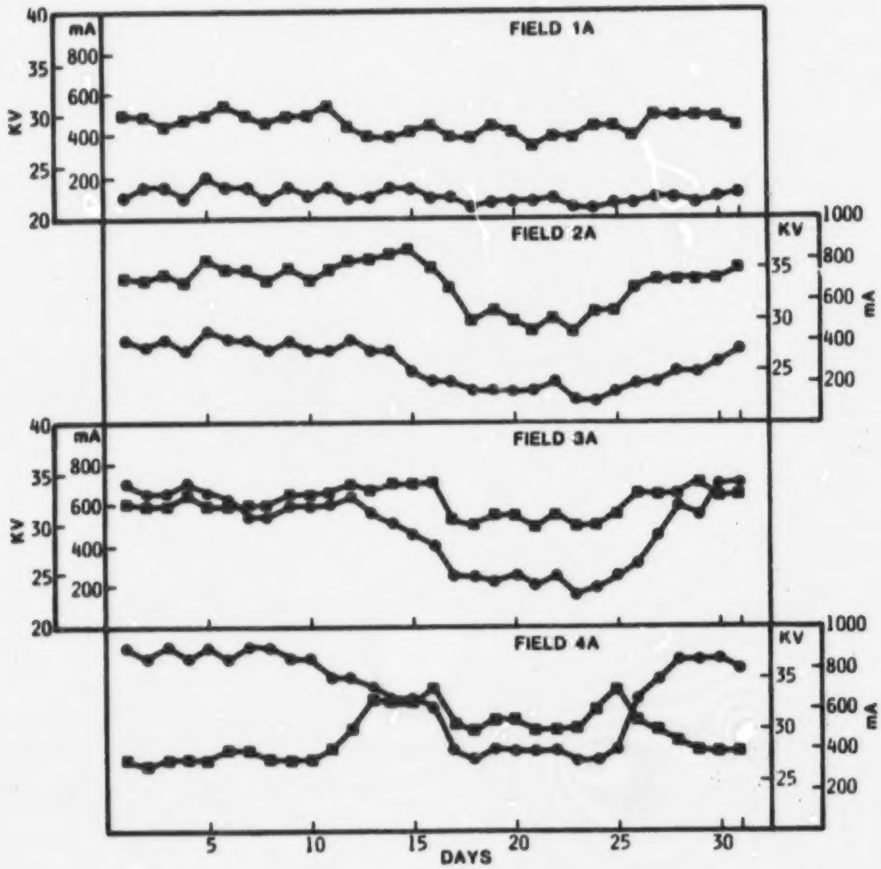

Figure 4-5b. Example of graphical displays of secondary current and voltage vs. day of operation.

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to see if the desired patterns exist. This presents a real problem on larger ESP's with many fields, but a relatively minor one on ESP's that have only three or four fields. Another advantage of this graphical method is that it permits the plotting of other parameters such as gas temperature, O_2 content, process load, opacity, and important feed characteristics. This capacity may provide correlating data to help diagnose the source of any problems that occur. For example, consider an ESP on a utility boiler that normally burned coal with a 0.8 and 1.0 percent sulfur content. When a coal with a lower sulfur content was introduced because normal coal supplies were interrupted, the effects of the change on ESP performance were visible within 24 hours when plotted on a time chart. Although the use of this coal was terminated after two weeks, it took several months of operation before the ESP returned to its normal performance level. Although the classic symptoms of high resistivity due to the lower sulfur content were identifiable from the meter readings, the severity of the effects of this process change on the ESP was much more visible in the trend graphs than in the tabular data gathered during each shift.

Other data that should be collected from the T-R cabinets include spark rate, evaluation of abnormal or severe sparking conditions, controller status (auto or manual), and identification of bus sections out of service. This additional information helps in the evaluation of ESP performance.

Air Load/Gas Load V-I Curves--

In addition to the routine panel meter readings, other electrical tests of interest to personnel responsible for evaluating and maintaining ESP's include the air load and gas load V-I (voltage-current) tests, which may be conducted on virtually all ESP's. Air load tests are generally conducted on cool, inoperative ESP's through which no gas is flowing. This test should be conducted when the ESP is new, after the first shutdown, and everytime off-line maintenance is performed on the ESP. These airload V-I curves serve as the basis for comparison in the evaluation of ESP maintenance and performance. A typical air load curve is shown in Figure 4-6.

Generating a V-I curve, a simple procedure, can be done with either primary or secondary meters. A deenergized T-R set on manual control is energized (but with zero voltage and current), and the power to the T-R set

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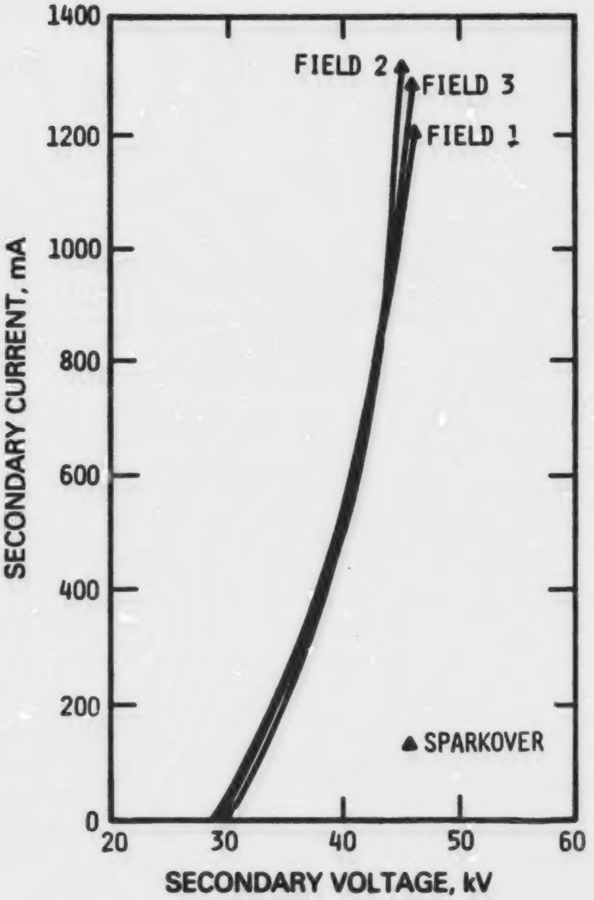

Figure 4-6. Typical air-load test V-I curve for an ESP on a recovery boiler with normal dust layer.

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is increased manually. At corona initiation the meters should move suddenly and the voltage and near zero current level should be recorded. (It is sometimes difficult to identify this point precisely, so the lowest practical value should be recorded.) After corona initiation is achieved, the power should be increased at predetermined increments, say, every 50 or 100 milliamps of secondary current or every 10 volts of AC primary voltage (the increment is discretionary), and the values recorded. This procedure should be continued until either sparking occurs, the current limit is achieved, or the voltage limit is achieved. This procedure is then applied to each T-R. One difficulty that sometimes arises is activation of the undervoltage trip circuit in the control cabinet. Either increasing the time for response or decreasing the activation voltage will prevent the T-R from tripping out during the test. This problem is worse with some T-R cabinet designs than with others.

When the air-load tests have been completed for each field, the voltage/current curves are plotted. When ESP's are equipped with identical fields throughout, the curves for each field should be nearly identical. The curves should be similar for ESP's with varying field dimensions or T-R sizes. In most cases, the curves also should be similar to those generated when the unit was new, but shifted slightly to the right because of dust on the wires and plates. These curves should become part of the permanent record on the ESP. This effect is demonstrated in Figures 4-7 and 4-8.

The use of the air-load curves enables plant personnel to identify which field(s) may be experiencing difficulty. Comparison with an air-load test run just before a unit is serviced will confirm whether the maintenance work corrected the problem(s). A check should be made to be sure all tools, soda cans, rags, raincoats, and magazines are removed from the ESP prior to its startup.

The advantage of air-load tests is that because they are performed under near identical conditions each time, curves can be compared. One of the disadvantages is that the internal conditions are not always the same as during normal operation. For example, misalignment may appear or disappear when the ESP is cooled (expansion/contraction), and dust buildup may be removed by rapping during ESP shutdown.

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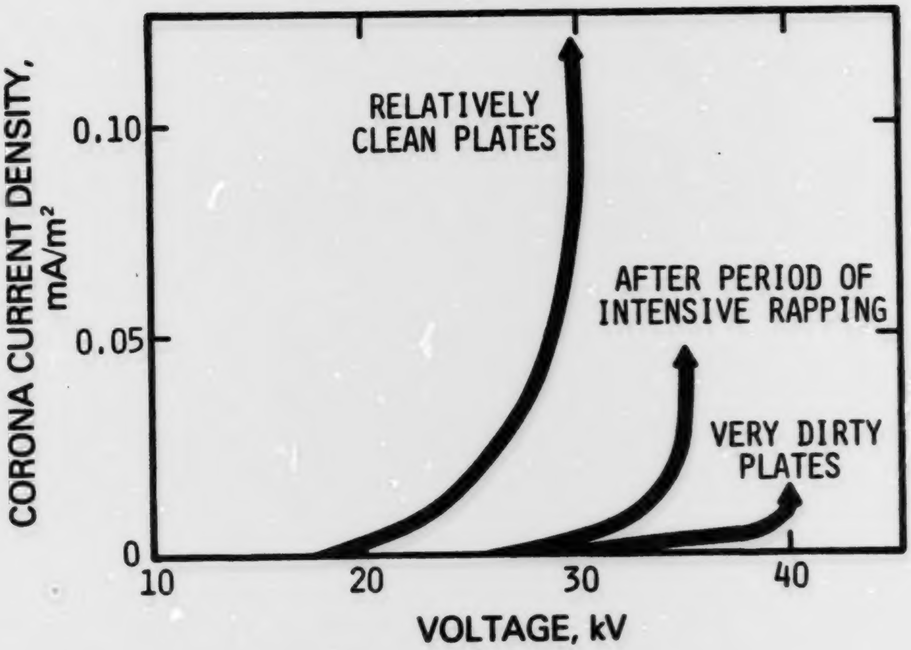

Figure 4-7. Variation of voltage current characteristics with collecting plate contamination.

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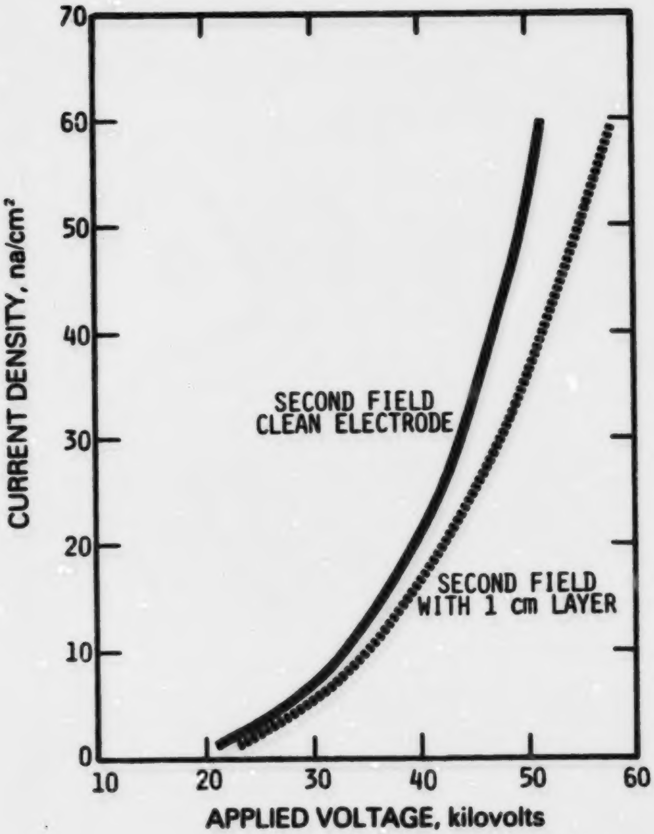

Figure 4-8. Effect of dust layer thickness on V-I curve.[1]

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The gas load V-I curve, on the other hand, is generated during the normal operation of the process while the ESP is energized. The procedure for generating the V-I curve is the same except that gas-load V-I curves are always generated from the outlet fields first and move toward the inlet. This prevents the upstream flow that is being checked from disturbing the V-I curve of the downstream field readings. Although such disturbances would be short-lived (usually 2 minutes, but sometimes up to 20 minutes), working from outlet to inlet also speeds up the process.

The curves generated under gas load will be similar to air-load curves. They will generally be shifted to the left under gas load conditions, however, and the shape of the curve will be different for each field depending on the presence of particulate in the gas stream (see Figure 4-9).

The pattern in the V-I curves under gas load conditions is similar to what is shown in Figure 4-9. As shown, the gas-load curve is to the left of the air-load curve. Both curves shift to the left from inlet to outlet (characteristic of most ESP's operating under moderate resistivity). The end point of each curve is the sparking voltage/current level, or maximum attainable by the T-R. These points represent the characteristic rise in current from inlet to outlet that is normally seen on the ESP panel meters. Problems characterized by the air load curves will normally also be reflected in the gas-load curve, but some problems may show up in one set of curves and not in the other (e.g., high resistivity as shown in Figure 4-10, some misalignment problems).

Another item of importance is that gas-load curves vary from day to day, even minute by minute. Curve positions may change as dust builds up and is then removed from the plates; as gas flow, particulate chemistry loading, and temperature change; and as resistivity changes (for examples, see Figures 4-11 and 4-12). Nonetheless, they still should maintain a characteristic pattern. Gas-load curves are normally used to isolate the cause of a suspected problem rather than on a day-to-day basis; however, they can be used daily if necessary. Several facilities equipped with analog T-R controllers manually set the voltage/current limits every shift because the controllers find it difficult to recognize the back corona conditions of their high resistivity dust. By establishing where back corona begins, plant personnel are able to

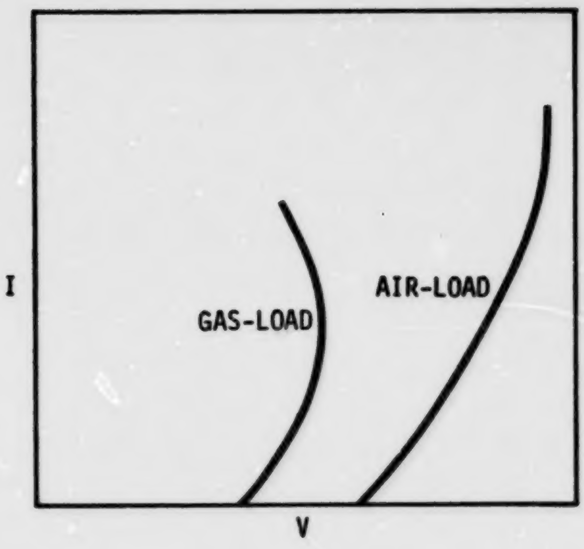

Figure 4-9. Comparison of typical air load and gas load V-I curves.

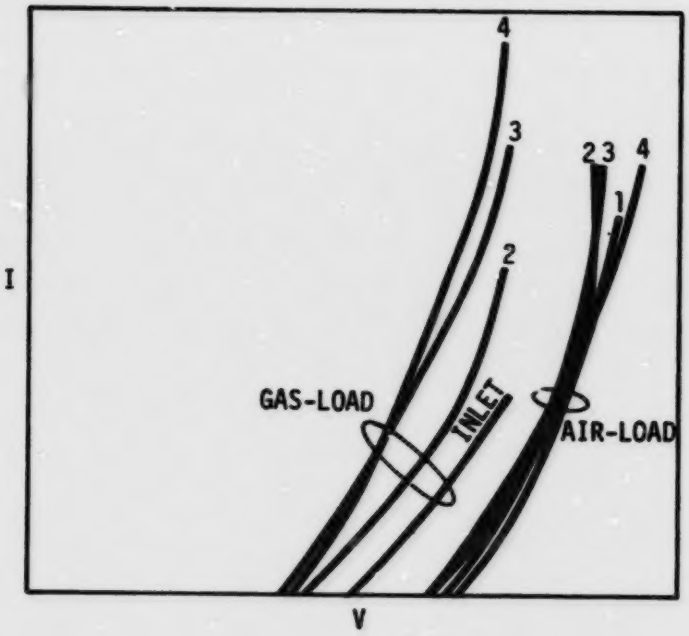

Figure 4-10. Comparison of V-I curves for high resistivity at air load and gas load conditions.

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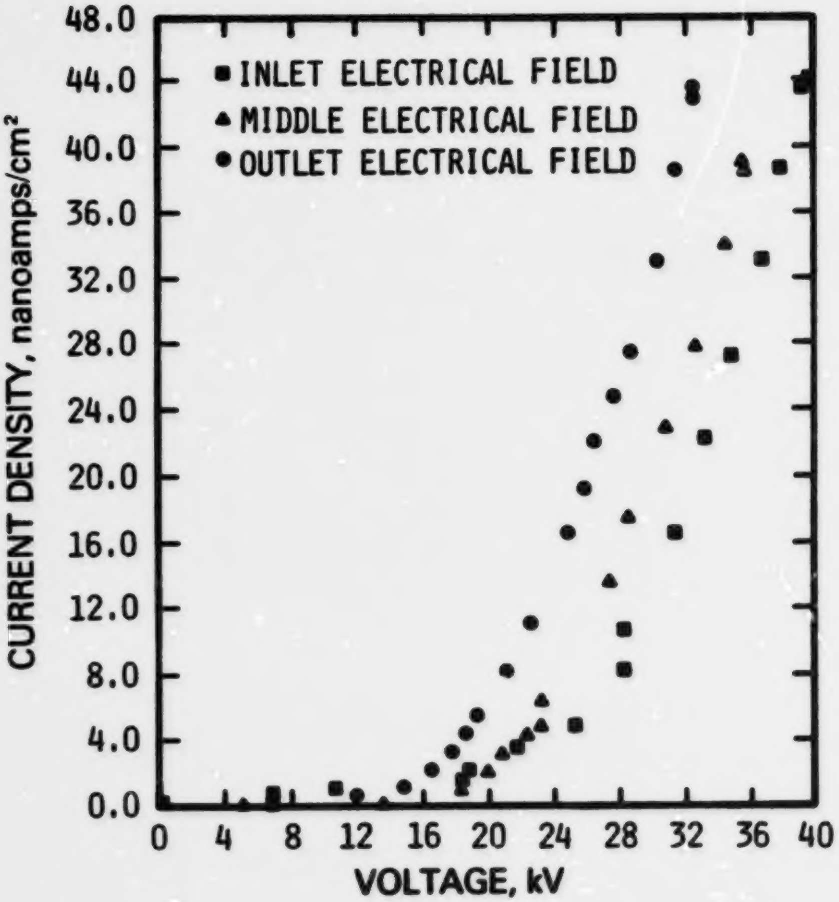

Figure 4-11. V-I curves demonstrating particulate space charge effect in a cold side precipitator collecting fly ash.[1]

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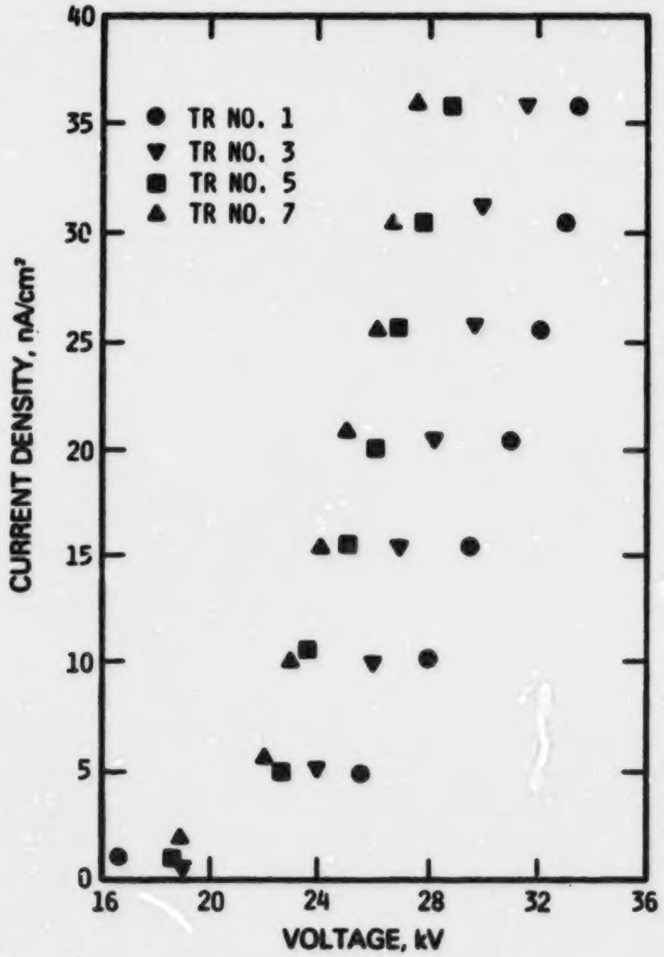

Figure 4-12. Typical V-I curves for a cold side ESP operating at moderate ash resistivity.[1]

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obtain the maximum voltage and current possible without wasting power or degrading ESP performance.

Other possible data that could aid in the evaluation of trends and long-term performance include a plot of wire failures within the ESP and their frequency, frequency of hopper pluggage, and a plot of the percent of the ESP deenergized on a daily basis. This last item can be used in combination with opacity and electrical data to define when maintenance work is needed and whether it is addressing the problems encountered, and to aid in the scheduling of routine and preventive maintenance.

It is evident that obtaining good operating data and maintaining good records help in the maintenance of ESP performance by providing a historical data base that can be used to evaluate daily operating performance. Recordkeeping alone, however, will not guarantee satisfactory long-term performance. Analysis of the data and an understanding of the fundamental design features and limitations and the operating characteristics of the ESP are necessary to correct minor problems before they become major.

4.2 PROBLEM DIAGNOSIS

Many ESP operating problems are reflected in the electrical operating characteristics. In a typical, well-designed, operated, and maintained ESP (without resistivity problems), a pattern of increasing current and decreased sparking from the inlet to the outlet fields would be expected. The operating voltage may be somewhat low because of sparking at the inlet and increase in the second and third fields. The voltage may begin to drop as the gas approaches the outlet because the gas is relatively clean. Although this is not a problem in every ESP, the tendency in most ESP's is for the current to increase from inlet to outlet. It is important to be familiar with the operating characteristics of the ESP and to know what is typical. The recordkeeping discussed in Section 3 helps one to become more knowledgeable.

One of the difficulties in assessing ESP performance is that many different problems produce the same electrical characteristics on the panel meters. For this reason, plant personnel obtain additional data to reduce the number of possible causes to one or two. In addition, synergism often causes the original problem or failure to lead to additional problems that can cascade into even more problems. When this occurs, it is difficult to identify the original cause of a problem. Nevertheless, it is usually important to identify and correct all causal factors rather than to treat the symptom. Again, the key to diagnostic troubleshooting is to know the precipitator's characteristics; to understand what the meter readings mean; and to use all the process, opacity, and electrical data to assist in the evaluation. An internal inspection may even be necessary to confirm or eliminate possible sources of problems (Section 6.0).

Most major performance problems can be categorized into the following areas: resistivity, hopper pluggage, air inleakage, dust buildup, wire breakage, rapper failure, inadequate power supplies and/or plate area, changes in particle size, and misalignment of ESP components. Some of these problems are related to design limitations, operational changes, maintenance procedures, or a combination thereof. The identification of these problems and their effect on ESP performance are discussed here; possible corrective measures are discussed later (in Section 4.3).

4.2.1 Problems Related to Resistivity

The concept of resistivity and its effect on ESP design were introduced earlier. Briefly, the resistivity of the dust on the collection plate affects the acceptable current density through the dust layer, the ability to remove the dust from the plates, and indirectly, the corona charging process. Much attention has been given to high resistivity conditions in utility fly ash applications. Because the optimum resistivity range for ESP operation is relatively narrow, however, both high and low resistivity cause problems. When a unit is designed with modest plate area, sectionalization, and power-input capabilities, poor ESP performance can result from excursions outside the optimum resistivity range. At sources where resistivity changes are intermittent, modification of operating procedures may improve performance temporarily. At sources where the dust remains outside the design resistivity characteristics, however, expensive retrofitting or modification may be required.

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High Resistivity--

The most common resistivity problem is that caused by high dust resistivity. Because of their inability to release or transfer electrical charge, the particles acquire charge from the corona charging process and migrate to the collection plate. Once at the collection plate, the particles neither give up very much of their acquired charge nor easily pass the corona current to the grounded collection plates. As the dust layer buildup continues, the resistance to current flow increases, and the controller responds by "opening up" the SCR more to increase the voltage level. This is demonstrated in the V-I curve presented in Figure 4-13. Although this would occur with almost all particulates, the detrimental effect on ESP performance is more pronounced when particle resistivity is high.

The voltage drop across the dust layer may be substantial. The dust layer voltage drop (which depends on the resistivity and thickness of the dust layer) can be approximated by Ohm's law. As the current increases, the voltage drop also increases. Under high resistivity conditions, however, very high voltage drops may occur at low current density; when the voltage drop exceeds 15 to 20 kV/cm, the dust layer will break down electrically. As the resistivity climbs, the current level at which this breakdown occurs decreases. It is this breakdown of the dust layer that diminishes the ESP performance.

The optimum resistivity range is generally between 10^8 and 10^{10} ohm-cm. Performance of the ESP generally does not diminish until approximately 2 x 10^{11} ohm-cm. High-temperature gas streams at the 600° to 700°F level could possibly exhibit resistivity problems at 10^{10} ohm-cm because of low gas density. Conversely, high altitudes will also tend to reduce the resistivity level at which problems may occur. At this level the breakdown of the dust layer may be limited, but it can be aggravated by unequal buildup on the plates, and the response of the controller to increase the operating voltage may exceed the voltage required for spark propagation. Thus, when the dust layer does break down, the resistance to current flow is suddenly reduced and a spark is formed. An identifying characteristic of high resistivity is the tendency toward high spark rates at low current levels throughout the ESP,

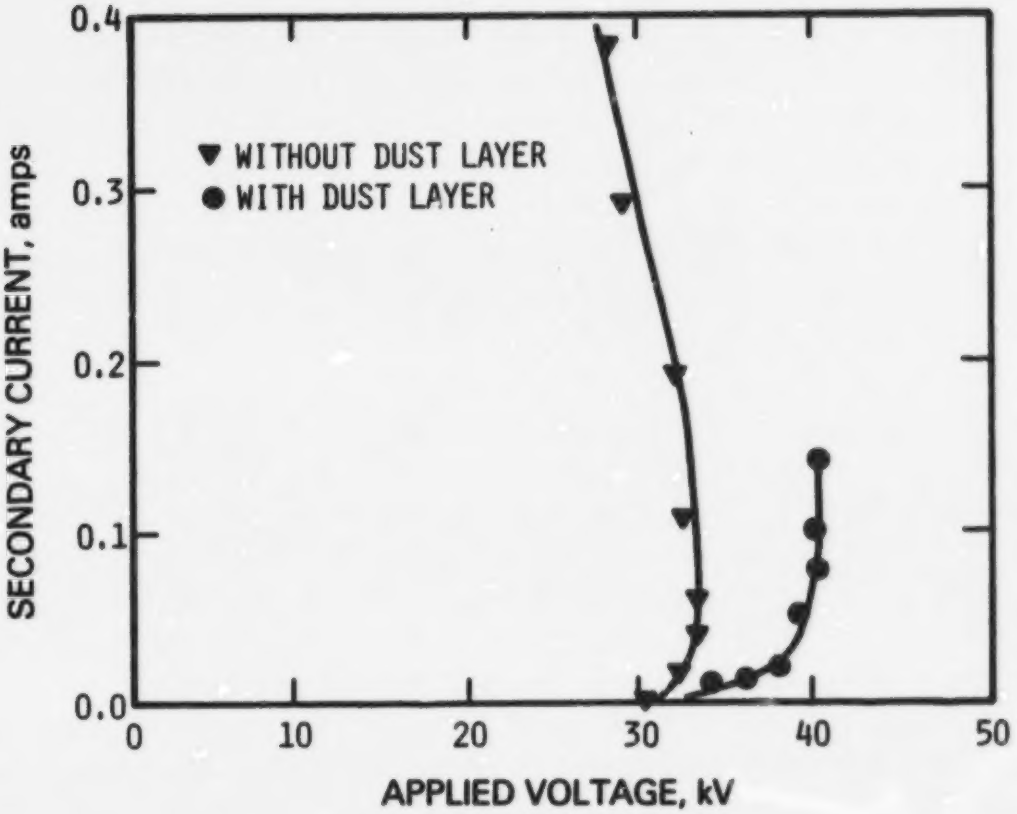

Figure 4-13. V-I characteristics of inlet section of ESP collecting high resistivity ash.

which often makes it difficult for the T-R controller to respond and function adequately.

As the resistivity climbs well into the 10^{13} ohm-cm range, the sparking may be sharply reduced or become nonexistent because the dust layer voltage exceeds the breakdown threshold at such low current density that insufficient voltage is applied to the wire to propagate a spark across the interelectrode space. Also, the breakdown of the dust layer may be widespread across the plate. This condition, known as "back-corona," is characterized by a discharge of positive ions from the plates that may reduce the charging of particles and even reduce the voltage below the level of negative corona initiation. Although back-corona is more pronounced and well developed at higher resistivities, it also occurs during sparking. In the latter case it is somewhat limited to small "craters" that form on the plate opposite the wires.

Severe sparking can cause excessive charging off-time, spark "blasting" of particulate of the plate, broken wires due to electrical erosion, and reduced average current levels. It is the reduced current levels that generally lead to deteriorated performance. Because the current level is indicative of the charging process, the low current and voltage levels that occur inside an ESP operating with high resistivity dust generally reflect slower charging rates and smaller voltage forces applied to the dust to force migration to the plate. The effect is an undersized ESP; if high resistivity is expected to continue, the design could be modified to accommodate this problem and thereby improve performance.

High resistivity also tends to promote rapping problems, as the electrical properties of the dust tend to make it very tenacious. High voltage drop through the dust layer and the retention of electrical charge by the particles make the dust difficult to remove because of its strong attraction to the plate. In addition to the reduced migration and collection rate associated with high resistivity dust, greater rapping forces usually required to dislodge the dust may also aggravate or cause a rapping reentrainment problem. Important items to remember are 1) difficulty in removing the high-resistivity dust is related to the electrical characteristics, not to the

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sticky or cohesive nature of the dust; and 2) the ESP must be able to withstand the necessary increased rapping forces without sustaining damage to insulators or plate support systems. Figure 4-14 shows an example V-I curve for an ESP field with insulator tracking (i.e., current leakage) problems.

Low Resistivity--

Low dust resistivity can be just as detrimental to the performance of an ESP as high resistivity. Low resistivity refers to the inability of particles to retain a charge once they have been collected on the plate. As in the normal- and high-resistivity cases, the ability of the particulate matter to obtain a charge is not affected by its resistivity; particle charging occurs by the previously discussed charging mechanisms, which are dependent on particle size. Once the particles are at the collection plate, however, they release much of their acquired charge and are capable of passing the corona current quite easily. Thus, attractive and repulsive electrical forces that are normally at work at higher resistivities are lacking, and the binding forces ("holding power") to the plate are considerably lessened. Particle reentrainment is a substantial problem at low resistivity, and ESP performance appears to be very sensitive to contributors of reentrainment, such as poor rapping or poor gas distribution.

The voltage drop across the dust layer on the plate is usually small. The lower resistance to current flow than in the optimum- and high-resistivity ranges means lower operating voltages are required to obtain substantial current flow. Thus, operating voltages and currents are typically close to clean plate conditions, even when there is some dust accumulation on the plate. A typical low-resistivity condition, then, is characterized by low operating voltages and high current flow, which would be reflected in the T-R panel meter readings. These electrical conditions may look very similar to those of high resistivity with well-developed back-corona. In any case, the result is usually the same--reduced ESP performance.

Despite the large flow of current under the low-resistivity conditions, the corresponding low voltages yield lower migration velocities to the plate. Thus, particles of a given size take longer to reach the plate than would be expected. When combined with substantial reentrainment, the result is poor

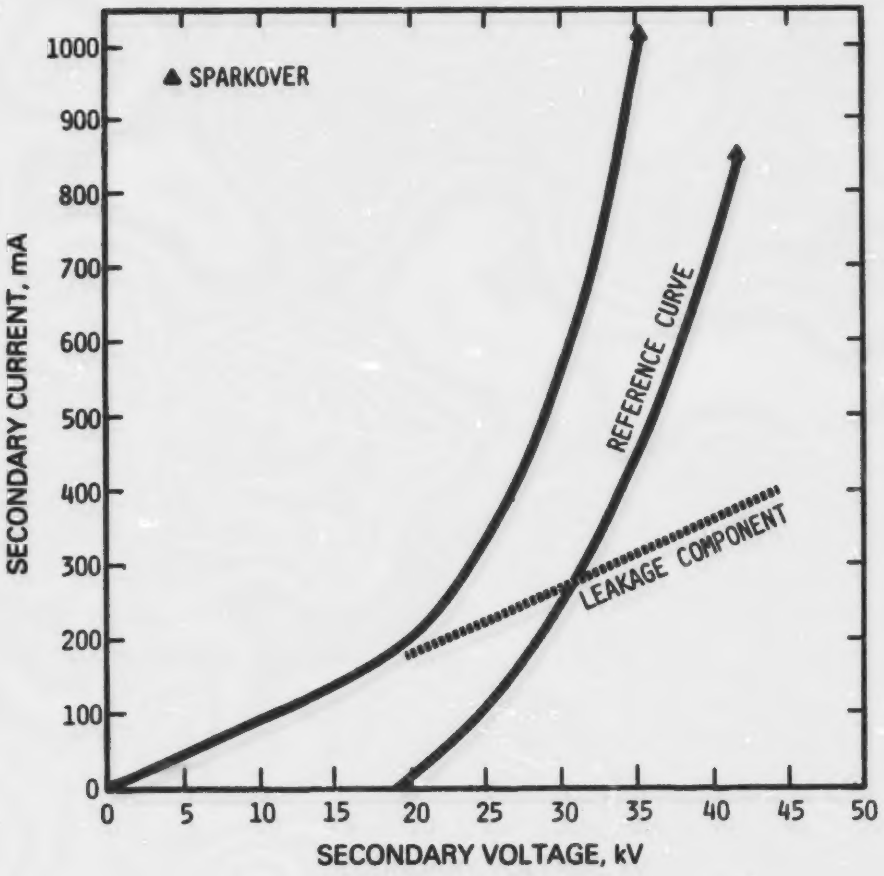

Figure 4-14. Air load V-I curve for ESP field with insulator tracking.

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ESP performance. In this case, the large flow of power to the ESP represents a waste of power.

The low-resistivity problem typically results from the chemical characteristics of the particulate and not from temperature. The particulate may be enriched with compounds that are inherently low in resistivity, either because of poor operation of the process or the inherent nature of the process. Examples of such enrichment include excessive carbon levels in fly ash (due to poor combustion), the presence of naturally occurring alkalies in wood ash, iron oxide in steel-making operations, or the presence of other low-resistivity materials in the dust. Over-conditioning may also occur in some process operations, such as the burning of high-sulfur coals or the presence of high SO_3 levels in the gas stream, which lower the inherent resistivity of the dust. In some instances, large ESP's with SCA's greater than 750 ft^2/1000 acfm have performed poorly because of the failure to comprehend fully the difficulty involved in collecting a low-resistivity dust. Although some corrective actions are available, they are sometimes more difficult to implement than those for high resistivity. Fortunately, the low-resistivity problem is not as common as the high-resistivity problem.

4.2.2 Excessive Dust Accumulations on Electrodes

Where no ash resistivity problem exists, the cause for excessive dust accumulation in an ESP is often external. When buildup of material on the discharge electrodes and collecting electrodes or plates is difficult to distinguish in an operating ESP, differences in the V-I curves can often point up the nature of the problem (see Figure 4-15).

Buildup of material on the discharge electrodes (whether straight-wired, barbed-wired, or rigid) often means an increase in voltage to maintain a given operating current. The effect of dust buildup on the discharge electrodes is usually equivalent to changing the effective wire size diameter, and since the corona starting voltage is strongly a function of wire diameter, the corona starting voltage tends to increase and the whole V-I curve tends to shift to the right. Sparking tends to occur at about the same voltage unless resistivity is high. This effect on corona starting voltage is usually more pronounced when straight wires are uniformly coated with a heavy dust, and less pronounced on barbed wires and rigid electrodes or when the dust layer

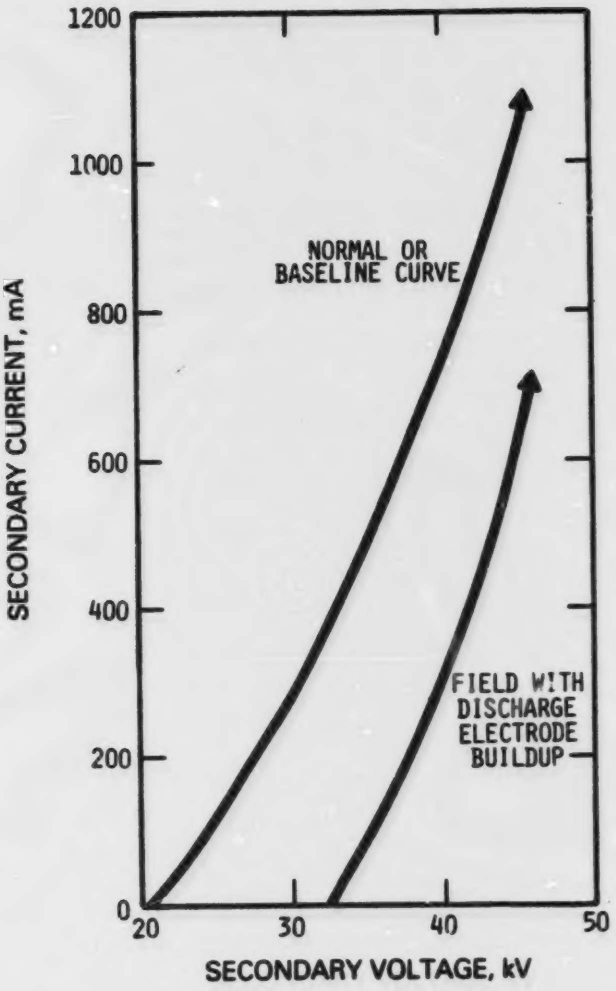

Figure 4-15. V-I curve for a field with excessive wire buildup.

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is not uniform. Barbed wires and rigid electrodes tend to keep the "points" relatively clean and to maintain a small effective wire diameter and, therefore, a low corona starting voltage. Nevertheless, a higher voltage would still be required to overspread the wire with the corona discharge where the wire buildup had occurred. Thus, buildup on the discharge electrodes would still be characterized by a higher voltage to maintain a given current level.

Under normal operating conditions, most of the dust would be collected at the plate and relatively little would collect on the wires. The dust that collects on the wires is usually the dust that enters the corona discharge area with the proper trajectory to attach to the wire. The material collected on the plate is usually allowed to build up for some specified length of time to take advantage of certain cohesive forces between particles and then dislodged by activation of a rapper. This dust buildup usually changes the electrical characteristics of the field and causes a shift in voltage and current over the period of the buildup. This variation in the amount of dust on the plates is one reason why readings of panel meters may vary from observation to observation. In general, however, dust buildup on a clean plate (as on electrode wires) increases the voltage to maintain a given current level. This effect is normally most apparent on a middle or outlet field of an ESP, where the time between rapping periods is sufficiently long to allow a substantial dust layer to build up. Electrical readings taken just before and just after a rapping cycle should indicate decreased operating voltage (as reflected by the primary voltmeters) and a decreased or constant current level. The dust layer presents a resistance to the current flow, and the operating voltage must be increased to overcome this resistance. The dust layer has relatively little effect on corona starting voltage.

If the dust layer buildup were relatively even, it might be expected to continue up to the T-R set capacity. In practice, however, dust buildup usually reaches a thickness of between 3/4 and 1 in. under normal resistivity conditions before performance is markedly reduced. As the thickness increases and operating voltages increase, however, the clearance between the discharge electrode and the surface of the dust layer diminishes, which encourages a sparking condition within the precipitator. The precipitator controls then respond by decreasing operating voltage and current, which lowers the

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charging and migration rates. This in turn causes the volume occupied by the ash within the precipitator to increase, and the gas velocity between the plates must also increase to maintain a given flow rate. If the increased velocity exceeds 6 to 8 ft/s, reentrainment is likely to occur and reduce performance further. In some cases the dust layer will become self-limiting because of the gas velocity through the ESP.

The usual cause for buildup on the collection plates or discharge wires is failure of the rapping system or an inadequate rapping system. The rapping system must provide sufficient force to dislodge the dust without damaging the ESP or causing excessive reentrainment. The failure of one or two isolated rappers does not usually degrade ESP performance significantly. The failure of an entire rapper control system or all the rappers in one field, however, can cause a noticeable decrease in ESP performance, particularly with high-resistivity dust. Therefore, rapper operation should be checked at least once per day, or perhaps even once per shift. A convenient time to make this check is during routine T-R set readings.

Rapper operation may be difficult to check on some ESP's because the time periods between rapper activation can range from 1 to 8 hours on the outlet field. One method of checking rapper operation involves installing a maintenance-check cycle that allows a check of all rappers in 2 to 5 minutes by following a simple rapping pattern. The cycle would be activated by plant personnel, who would interrupt the normal rapping cycle and note any rappers that fail to operate. After the cycle, the rappers would resume their normal operation. Maintenance of rapper operation is important to optimum ESP performance. (Note: In rare cases, rapping is not necessary. These usually involve low-resistivity dust that requires very little energy to remove or actually dislodges from its own weight. Also, no rappers are associated with the collection surface in wet ESP's, but they may be used for the discharge electrodes.)

Excessive dust buildup also may result from sticky dusts or dewpoint conditions. In some cases, the dusts may be removed by increasing the temperature, but in many cases the ESP must be entered and washed out. If sticky particulates are expected (such as tars and asphalts), a wet-wall ESP is usually appropriate because problems can occur when large quantities of sticky particles enter a dry ESP. Among the cases where this may be a problem are ESP's applied to wood-fired boilers, municipal incinerators, and some coal-fired boilers. The problem usually occurs when improper combustion yields a partially combusted, sticky, hydrocarbon material. This can also present a fire hazard and potential low-resistivity problems. Some utilities have also experienced the problem when an ESP was energized while the oil guns were still in use during startup or when stable operation had not yet been achieved.

Sticky particulate can also become a problem when the temperature falls below dewpoint conditions. Although acid dewpoint is usually of greater concern in most applications, moisture dewpoint is important. When dewpoint conditions are reached, liquid droplets tend to form that can bind the particulate to the plate and wires (and also accelerate corrosion). Carryover of water droplets or excessive moisture can also cause this problem (e.g., improper atomization of water in spray cooling of the gas or failure of a waterwall or economizer tube in a boiler). In some instances the dust layer that has built up can be removed by increasing the intensity and frequency of the rapping while raising the temperature to "dry out" the dust layer. In most cases, however, it is necessary to shut the unit down and wash out or chisel out the buildup to clean the plates. Localized problems can occur where inleakage causes localized decreases in gas temperature.

In the pulp and paper industry, sticky particulate has been noted during periods of high excess air levels in recovery boilers burning black liquor. Concentrations of SO_3 tend to increase. These result in a raised acid dewpoint, since the SO_2 is absorbed on the particulate at the relatively low temperatures in the economizer and ESP. This sticky salt cake can be difficult to remove from both the economizers and ESP's. The situation can be further aggravated by the combustion of residual fuel oil containing vanadium. The vanadium oxides with SO_2 in the gas stream, and excess O_2 tends to convert greater quantities of SO_2 to SO_3 than would naturally occur. The sodium/vanadium salt complexes formed can also make it more difficult to remove the salt cake. Some of the vanadium complexes may also be insoluble in water and be difficult to wash off the plates during an ESP washdown.

4.2.3 Wire Breakage

Some ESP's operate for 10 to 15 years without experiencing a single wire breakage, whereas others experience severe problems causing one or more sections to be out of service nearly every day of operation. Much time and effort have been expended to determine the causes of wire breakage. One of the advantages of a rigid-frame or rigid-electrode ESP is that this type uses shorter wires or no wires at all. Although most of the new ESP's are of the rigid-frame and rigid-electrode type (and some weighted-wire systems have also been retrofitted to rigid electrode), the most common ESP in service today is still the weighted-wire; therefore, the nature, severity, and locations of wire failures cannot be overlooked.

Wires usually fail in one of three areas: at the top of the wire, at the bottom of the wire, and wherever misalignment or slack wires reduce the clearance between the wire and plate. Wire failure may be due to electrical erosion, mechanical erosion, corrosion, or some combination of these. When wire failures occur, they usually short-out the field where they are located, and in some cases, may short-out an adjacent field. Thus, the failure of one wire can cause the loss of collection efficiencies in an entire field or bus section. In some smaller ESP applications, this can represent one-third to one-half of the charging/collecting area and thus substantially limit ESP performance. One of the advantages of higher sectionalization is that wire failure affects smaller areas so ESP performance does not suffer as much. Some ESP's are designed to meet emission standards with some percentage of the ESP deenergized, whereas others may not have any margin to cover downtime. Inlet fields are usually more important to ESP operation than outlet fields.

Sparking usually occurs at points where there is close clearance within a field (due to a warped plate, misaligned guidance frames, or bowed wires). The maximum operating voltage is usually limited by these close tolerance areas because the spark-over voltage is lowered by the reduction in the distance between the wire and the plate. Under normal circumstances random sparking does little damage to the ESP. During sparking, most of the power supplied to energize the field is directed to the location of the spark, and the voltage field around the remaining wires collapses. The considerable quantity of energy available during the spark is usually sufficient to vaporize a small quantity of metal. When sparking continues to occur at the same location, the wire usually "necks down" because of electrical erosion until it is unable to withstand the tension and it breaks. Misalignment of the discharge electrodes relative to the plates increases the potential for broken wires, decreases the operating voltage and current because of sparking, and decreases the performance potential of that field in the ESP.

Although the breakage of wires at the top and bottom where the wire passes through the field can be aggravated by misalignment, the distortion of the electrical field at the edges of the plate tends to be the cause of breakage. This distortion of the field, which occurs where the wire passes the end of the plate, tends to promote sparking and gradual electrical erosion of the wires. The methods available to minimize this particular failure are discussed in Section 4.3.

Both design considerations and the failure to maintain alignment generally contribute to mechanical erosion (or wear) of the wire. In some designs, the lower guide frame guides the wires or their weight hooks (not the weights themselves) into alignment with the plates. When alignment is good, the guide frame or grid allows the wires or weight hooks to float freely within their respective openings. When the position of the wire guide frame shifts, however, the wire or weight hook rubs the wire frame within the particulate-laden gas stream. Failures of this type usually result from a combination of mechanical and electrical erosion. Corrosion may also contribute to this failure. Microsparking action between the guide frame and the wire or weight hook apparently causes the electrical erosion. The same type of failure also can occur in some rigid frame designs where the wires ride in the frame.

Another failure that sometimes occurs involves crossed wires. This happens when those who replace wires do not check to see that the replacement wire does not cross another wire. Eventually, the resulting wearing action breaks one or both wires. If one of the wires does survive, it is usually worn down enough to promote greater sparking at the point of contact until it finally does break. When wires are replaced, care should be taken to see that wires are not crossed. Any wires that are found to be exceptionally

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long and slack should be replaced; they should not be crossed with another wire to achieve the desired length.

Corrosion of the wires can also lead to wire failures. Corrosion, an electrochemical reaction, can occur for several reasons, the most common being acid dewpoint. When the rate of corrosion is slow and generally spread throughout the ESP, it may not lead to a single wire failure for 5 to 10 years. When the rate of corrosion is high because of long periods below the acid dewpoint, failures are frequent. In these cases the corrosion problem is more likely to be a localized one; e.g., in places where cooling of the gas stream occurs, such as inleakage points and the walls of the ESP. Corrosion-related wire failures can also be aggravated by startup/shutdown procedures that allow the gas streams to pass through the dewpoint many times. Many facilities have experienced wire breakage problems during the initial process shakedown period when the process operation may not be continuous. Once steady operation has been achieved, wire breakage problems tend to diminish at most plants. Some applications that routinely start up and shut down (small "peaking" utilities, for example) have had relatively few problems with wire breakage. Good operating practices and startup/shutdown procedures help to minimize this problem.

Another cause of wire failure is wire crimping. These crimps usually occur at the top and bottom of the wires where they attach to the upper wire frame or bottle weight; however, a crimp may occur at any point along the wire. A crimp can mechanically weaken and thin a wire, it can cause a distortion of the electric field along the wire and promote sparking, and it can subject the wire to a stress corrosion failure (materials under stress tend to corrode more rapidly than those not under stress). Because a crimp creates a residual stress point, all three mechanisms may be at work in this situation.

Wire failure should not be a severe maintenance problem or operating limitation in a well-designed ESP. Excessive wire failures are usually a symptom of a more fundamental problem. Plant personnel should maintain records of wire failure locations. Although ESP performance will generally not suffer with up to approximately 10 percent of the wires removed, these records should be maintained to help avoid a condition in which entire gas lanes may be deenergized. Improved sectionalization helps to minimize the effect of a broken wire on ESP performance, but performance usually begins to suffer when large percentages of the ESP are deenergized.

4.2.4 Hopper Pluggage

Perhaps no other problem (except fire or explosion) has the potential for degrading ESP performance as much as hopper pluggage. Hopper pluggage can permanently damage an ESP and severely affect both short-term and long-term performance. Hopper pluggage is difficult to diagnose because its effect is not immediately apparent on the T-R panel meters. Depending on its location, a hopper can usually be filled in 4 to 24 hours. In many cases, the effect of pluggage does not show up on the electrical readings until the hopper is nearly full.

The electrical reaction to most plugged hoppers is the same as that for internal misalignment, a loose wire in the ESP, or excessive dust buildup on the plates. Typical symptoms include heavy or "bursty" sparking in the field(s) over the plugged hopper and reduced voltage and current in response to the reduced clearance and higher spark rate. In weighted-wire designs, the dust may raise the weight and cause slack wires and increased arcing within the ESP. In many cases, this will trip the T-R off-line because of overcurrent or undervoltage protection circuits. In some situations, the sparking continues even as the dust builds between the plate and the wire; whereas in others, the voltage continues to decrease as the current increases and little or no sparking occurs. This drain of power away from corona generation renders the field performance virtually useless. The flow of current also can cause the formation of a dust clinker resulting from the heating of the dust between the wire and plate.

The buildup of dust under and into the collection area can cause the plate or discharge electrode guide frames to shift. The buildup can also place these frames under enough pressure to distort them or to cause permanent warping of the collection plate(s). If this happens, performance of the affected field remains diminished by misalignment, even after the hopper is cleared.

The causes of hopper pluggage include such things as obstructions due to fallen wires and/or bottle weights, inadequately sized solids-removal equipment, use of hoppers for dust storage, inadequate insulation and hopper heating, and inleakage through access doors. Most dusts flow best when they are hot, and cooling the dusts also can promote a hopper pluggage problem.

Hopper pluggage can begin and perpetuate a cycle of failure in the ESP. For example, in one ESP, a severely plugged hopper misaligned both the plates and the wire guide grid. When the hopper was cleared, the performance of this field had decreased and the wires and weight hooks were rubbing the lower guide and causing erosion of the metal. When the metal eventually wore through, hopper pluggage increased as weights (and sometimes wires) fell into the hopper, plugging the throat, and allowed the hopper to fill again and cause more misalignment. The rate of failure continued to increase until it was almost an everyday occurrence. This problem, which has occurred more than once in different applications, points out how one relatively simple problem can lead to more complicated and costly problems.

In most pyramid-shaped hoppers, the rate of buildup lessens as the hopper is filled (because of the geometry of the inverted pyramid). Hopper level indicators or alarms should provide some margin of safety so that plant personnel can respond before the hopper is filled. The rate of deposition in the hopper also will diminish when the top of the dust layer interferes with the electrical characteristics of the field, which reduces the collection efficiency. Lastly, reentrainment of the dust from the hopper can also limit how far up into the field the dust can go. Although buildups as deep as 4 ft have been observed, they usually are limited to 12 to 18 in. up from the bottom of the plates.

4.2.5 Misalignment

As mentioned several times in the previous sections, misalignment is both a contributor to and a result of component failures. In general, most ESP's are not affected by a misalignment of less than about 3/16 in. Indeed, some tolerance must be provided for expansion and contraction of the components. Beyond this limit, however, misalignment can become a limiting factor in ESP performance and is usually visually evident during an internal inspection of the ESP. Whether caused by warped plates, misaligned or skewed discharge guide frames, insulator failure, or failure to maintain ESP "box-squareness," misalignment reduces the operating voltage and current required for sparking. The V-I curve would indicate a somewhat lower voltage to achieve a low current level with the sparking voltage and current greatly reduced (see Figure 4-16). Since the maximum operating voltage/current levels are dependent on the path of least resistance in a field, any point of close tolerance will control these levels.

4.2.6 Unusually Fine Particle Size

Unusually fine particles present a problem if 1) the ESP was not designed to handle them, or 2) a process change or modification shifts the particle size distribution into the range where ESP performance is poorest. A shift in particle size distribution tends to alter electrical characteristics and increase the number of particles emitted in the light-scattering size ranges (opacity).

As was discussed in Section 2, there are two basic charging mechanisms: field charging and diffusion charging. Although field charging tends to dominate in the ESP and acts on particles greater than 1 micrometer in diameter, it cannot charge and capture smaller particles. Diffusion charging, on the other hand, works well for particles smaller than 0.1 micrometer in diameter. On particles between 0.1 and 1.0 micrometer in diameter, and particularly in the range of 0.2 to 0.5 micrometer, performance of the ESP diminishes considerably. Because neither charging mechanism is very effective, particles in this range are more difficult to charge; and once charged, they are easily bumped around by the gas stream, which makes them difficult to collect. The collection efficiency of an ESP can drop from as high as 99.9+ percent on particles sized above 1.0 micrometer and below 0.1 micrometer, to only 85 to 90 percent on particles in the 0.2- to 0.5-micrometer diameter range, depending upon the type of source being controlled. If a significant quantity of particles fall into this range, the ESP design must be altered to accommodate the fine particles.

Two significant electrical effects of fine particles are space charge and corona quenching, which occur when heavy loadings of fine particles enter the ESP. At moderate resistivities, the space-charge effects normally occur in the inlet or perhaps the second field of ESP's. Because it takes time to

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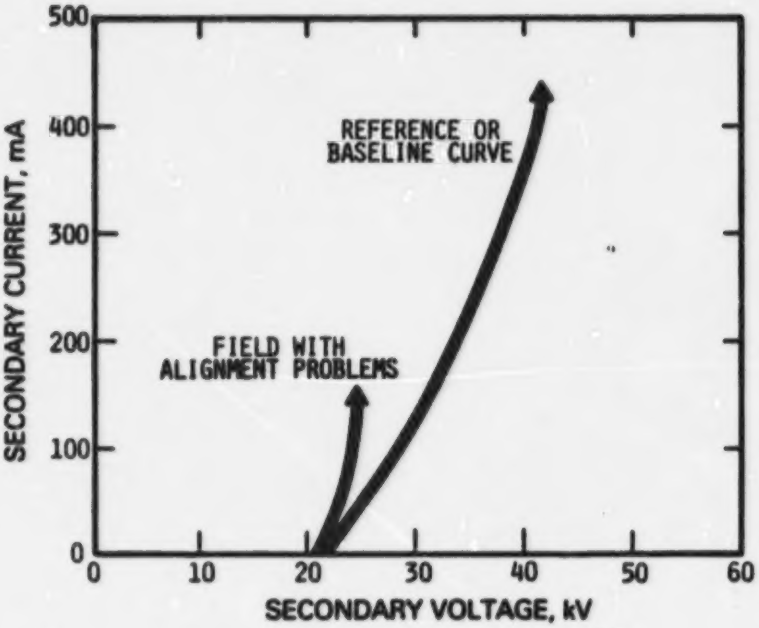

Figure 4-16. Air load V-I curve pattern generated by alignment problems.

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charge the particles and then to force them to migrate to the plate, a cloud of negatively charged particles forms in the gas stream. This cloud interferes with corona generation process and impedes the flow of ions from the wire to the gas stream. The T-R controller responds by increasing the operating voltage to maintain current flow and corona generation. The increase in voltage usually causes increased spark rates, which may in turn reduce the voltage and current to maintain a reasonable spark rate. As the particles move through the ESP and are collected by the plates, the gas stream becomes cleaner. As a result, the voltage level will usually decrease but current levels will increase markedly. As quantities of fine particles are increased, the space charging effect may progress further into the ESP.

Corona quenching can also result when the quantity of particles is so great that relatively few electrons even reach the plate in the inlet. This condition is characterized by very high voltages and extremely low current. An example of this type of situation would be a raw mill where an ESP is used to control particulates from a preheater or precalcining kiln and all of the material leaving the mill's preheater/precalciner enter the ESP. Grain loadings up to 165 to 200 gr/acf could be encountered, and the ESP must be able to handle this quantity of material.

4.2.7 Inleakage

Inleakage is often overlooked as an operating problem. In some instances, it can be beneficial to ESP performance, but in most cases its effect is detrimental. Some of the causes of inleakage, which may occur at the process itself or at the ESP, are leaking access doors, leaking ductwork, and even open sample ports.

Inleakage usually cools the gas stream, and it can also introduce additional moisture. The result is often localized corrosion of the ESP shell, plates, and wires. The temperature differential also could cause electrical disturbances (sparking) in the field. Finally, the introduction of ambient air can affect the gas distribution near the point of entry. The primary entrance paths are through the access doors. Inleakage through hopper doors may reentrain and excessively cool the dust in the hopper, which can cause both reentrainment in the gas stream and hopper pluggage. Inleakage through the access doors is normally accompanied by an audible in-rush of air.

Inleakage is also accompanied by an increase in gas volume. In some processes, a certain amount of inleakage is expected. For example, application of Lungstrom regenerative air heaters on power boilers or recovery boilers is normally accompanied by an increase in flue gas oxygen. For utility boilers the increase may be from 4.5 percent oxygen at the inlet to 6.5 percent at the outlet. For other boilers the percentage increase may be smaller when measured by the O_2 content, but 20 to 40 percent increases in gas volumes are typical and the ESP must be sized accordingly. Excessive gas volume due to air inleakage, however, can cause an increase in emissions due to higher velocities through the ESP and greater reentrainment of particulate. For example, at a kraft recovery boiler, an ESP that was designed for a superficial velocity of just under 6 ft/s was operating at over 12 ft/s to handle an increased firing rate, increased excess air, and inleakage downstream of the boiler. Because the velocities were so high through the ESP, the captured material was blown off the plate and the source was unable to meet emission standards.

4.2.8 Summary

Familiarity with ESP operating characteristics, failure modes, and design factors aid in the diagnosis of ESP performance. As pointed out in the discussion, many problems produce similar symptoms in T-R set meter readings. Gathering process data and generating V-I curves add data that are useful for diagnostic troubleshooting, but usually a process of elimination is necessary to narrow the possible causes of problems to one or two areas. To the extent possible, maintenance personnel should try to determine the cause of the problem, not merely treat a symptom. This approach often identifies the corrective actions necessary to avoid future problems, whereas the "band-aid" approach is more likely to cause more problems in the future. Recordkeeping is also very important in the evaluation of both short- and long-term ESP performance.

4.3 CORRECTIVE ACTIONS

When the data collected indicate that a problem exists, plant personnel must decide what action should be taken. Sometimes the initial cause of the problem is hard to define, even though results and symptoms clearly indicate its existence. In other cases, the problem is easily identifiable, but more than one choice for corrective action is available. The options available to plant personnel for the various problem areas discussed in Section 4.2 are presented here.

4.3.1 Correction of Resistivity-Related Problems

When examining the alternatives for correcting resistivity problems, plant personnel should ask three questions: 1) How often does this problem occur? 2) Can the process or materials be (economically, environmentally) changed to minimize or eliminate the problem? 3) Is the operation of the ESP optimal, or are there design limitations that cannot be overcome? The answers to these questions may eliminate certain options and enhance the feasibility of others.

For long-term resistivity problems, an option with high initial costs may be the most cost-effective when lost production and increased maintenance are considered. When resistivity problems are intermittent, however, changes in process operating parameters may offer a better solution.

One of the simplest changes in process operation is to raise or lower the gas temperature to increase either the surface conduction or bulk conduction mechanisms. This is particularly useful when the resistivity-versus-temperature curves are steep and have a relatively sharp peak. In some situations, a change of only 20° to 30°F may be all that is required to modify the resistivity and improve ESP performance. The disadvantages of changing the gas temperature include an increased potential for corrosion from acid dewpoint conditions if the temperature is lowered, and an increase in energy loss due to a higher gas temperature. The peak resistivity often occurs at or near the optimum temperature for the process. In addition, some multichambered ESP's may show symptoms of high resistivity in some chambers because of the difference in operating temperatures between chambers.

The addition of moisture to the gas stream may be an acceptable method for conditioning the gas stream and improving performance. The moisture changes the dewpoint levels, enhances the conduction of the particulate matter, and by increasing the dielectric strength of the gas, the electric field is less likely to break down and spark. The evaporation of water

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droplets used to condition the gas stream will also cool the gas stream and further condition it. The water droplets must be properly atomized to provide good evaporation without excessive water use or carryover into the ESP. This often requires the use of air-atomized sonic nozzles. In some ESP applications, the use of moisture conditioning is essential to the capture of particulate. Two examples are salt cake recovery in kraft mills and cement dust control in cement plants. Whether the presence of moisture is inherent to the process (as in the case of kraft recovery process or wet process cement kilns) or due to external addition (as in dry processes, some preheat situations, or precalciner cement kilns), the lack of moisture would make it difficult to capture the particulate matter because of its high resistivity.

Another alternative solution for ash resistivity problems involves a change in process feed or operation to modify the chemical characteristics of the dust to be captured. For example, the coal supply for coal-fired boilers could be changed or blended to change the resistivity characteristics of the fly ash (this may or may not include an increase in coal sulfur). A change or blending of coal may improve collection efficiency, but care must be taken to avoid boiler problems such as slagging or fouling of boiler tubes due to the incompatibility of ash and furnace conditions. Another alternative available to a boiler operator is to lower the combustion efficiency and allow more unburned carbon into the ESP. Although this may reduce boiler efficiency, the presence of small amounts of carbon can act as a conditioning agent and reduce the resistivity of the fly ash. The trade-off in some situations is worthwhile because the slight loss in efficiency is offset by the ability to maintain load rather than to reduce the load to maintain the opacity limitation. Care must be taken not to overuse this solution, however. In some processes, such as cement kilns or municipal incinerators, it may not be possible to change or control the feed characteristics to maintain acceptable resistivity characteristics.

Low-resistivity problems are often more difficult to correct. Low superficial gas velocities and optimization of rapper operation and rapping pattern can help to minimize reentrainment problems commonly encountered with low-resistivity dusts; however, generating the force necessary to keep the collected dust on the plates is difficult. If gas temperature is a problem, one alternative is to increase the temperature towards the peak resistivity. The problem is usually related to the process characteristics rather than gas temperature, however. Previously cited examples include high-sulfur fuel, excessive carbon levels, and the presence of natural but excessive levels of conditioning agents (e.g., alkalies) in the dust. Ash from wood combustion is a good example of this. Where possible, process changes will usually help--such as changing the fuel sulfur level or improving combustion efficiency to minimize the carbon content of the ash.

Conditioning agents have also been used to correct some low-resistivity problems. One of the better known applications is ammonia injection in gas streams containing large quantities of SO_2/SO_3. Although tests have indicated that (as in the high-resistivity cases) no apparent change occurs in resistivity, the agglomeration characteristic of particles on the plates changes and results in improved particle-to-particle cohesion. This helps to reduce the reentrainment problems that characterize low-resistivity dusts. In addition, the ammonia may react with flue gas constituents to form fine ammonium salt particles; e.g., ammonia combines with the SO_3 to form ammonium sulfate. These fine particles increase the space charge and cause higher operating voltages and the application of higher forces to the particles at the plates.

The resistivity-related problems associated with ESP's have been well studied in recent years, and the prediction of and design considerations for resistivity have become more precise. Some combination of corrective actions is usually available to the plant that experiences a high- or low-resistivity problem. Each corrective measure has both an economic and practical consideration, and site-specific factors will govern which options are chosen.

The remaining alternatives for correcting resistivity problems are more complex and more expensive. One of these is to retrofit additional ESP plate area to improve collection efficiency. This may entail the use of new designs, such as wide plate spacings. Retrofitting also may be difficult because of equipment placement and space limitations. Another alternative is to change the T-R sectionalization and perhaps to use low-power (secondary current limit) T-R's and/or pulse energization. The application of pulse energization, although commercially available, has been relatively limited.

The use of lower-power T-R's and increased sectionalization also can improve performance by matching electrical capabilities to the demands of high resistivity. The most common alternative, however, is the use of chemical conditioning to modify the resistivity characteristics of the particulate or to reduce their effects on ESP performance.

In addition to proprietary chemical additives, typical chemical additives include SO_3, sulfuric acid, ammonia, and soluble alkali salts. Most rely on the chemical additive to improve the surface conduction mechanism of charge transfer and to lower the effective resistivity of the particulate. (One exception to this is ammonia injection, which generally has little effect on dust resistivity, but may alter the electrical characteristics of the gas stream and the agglomerating characteristics of the ash on the plates. The effects are often unpredictable. This has been used more on low-resistivity problems caused by high-sulfur fuels.) The quantities of chemical additives required and their effectiveness vary; however, in a typical coal boiler application where the SO_3 option is often selected, the concentration required ranges from 8 to 40 ppm. This combination has been very successful, and some new ESP systems are being installed with a conditioning system and smaller SCA as an economic alternative to large-SCA ESP's (without conditioning) or fabric filters.

4.3.2 Correction of Sodium Depletion Problems

Options are available for solving the sodium depletion problem noted in Section 2 for hot-side ESP's at some utility boilers. Although periodic washdown restores the ESP performance to acceptable levels, it is not an altogether acceptable solution to the problem for most utilities. One analogous solution that has been proposed is the modification of the rapping system to rap the plates clean and remove the sodium-depleted ash layer at the plate surface. The modification may have to be substantial, as not all ESP's can withstand the high rapping forces necessary to cover the entire plate, nor can all rapping designs supply it. It may be an alternative on new ESP's, however, although high-intensity rapping alone is not likely to be an effective solution to sodium depletion.

Several methods of ash conditioning have been attempted with varying success. Because the electrical conduction mechanism in the ash layer of a

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hot-side ESP is bulk conduction at normal operating temperatures, it relies on alkali materials such as sodium to serve as electron carriers. As the sodium content of the ash becomes depleted, resistivity increases. The conditioning methods replace this sodium, usually with sodium carbonate, and thereby reduce the resistivity. Two methods of introduction have been attempted: introduction into the furnace zone with the coal and injection into the flue gas preceding the ESP.

Although the injection of dry sodium carbonate into the gas stream has provided some improvement in performance, large quantities of sodium carbonate may be required to effect reportedly small improvements. The addition of 1 to 2 lb/ton of coal to condition the ash produced in the furnace zone has been more successful. The sodium apparently becomes homogeneously mixed in the ash and thus is more effective in reducing the sodium depletion. The basic premise of this conditioning method is that the higher concentration of sodium in the dust layer increases the diffusion of sodium towards the plate and overcomes the electrically related diffusion away from the plate. Although primarily a high-temperature phenomenon, sodium depletion apparently can occur at lower temperatures as well, but it is not nearly as severe.

Boiler slagging is one of the problems associated with boiler operation when the sodium is mixed with the fuel. The increase in alkalies, particularly sodium, tends to lower the ash fusion temperature. At full load, the ash becomes liquid in the furnace and causes all sorts of operating difficulties. The heat release rates become too high for the new ash characteristics, and the rate must be dropped to cool the furnace. At some stations, this may mean derating the load by 20 to 35 percent, and unfavorable economics may result. The balance point between load reduction and sodium depletion is sometimes difficult to establish in these situations, particularly when coal characteristics vary widely.

4.3.3 Corrective Actions for Dust Accumulation Problems

The most common cause of excessive dust accumulation on the electrodes is failure of the rapper-control system. Unless there is reason to suspect otherwise (e.g., known high resistivity potential or other indications of hopper pluggage), this should be one of the first areas checked if power

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input into the ESP decreases markedly. This problem is relatively easy to rectify.

Rapper failures may involve individual rappers, entire electrical fields, or the entire ESP. Although isolated rapper failures are usually not severe, they can affect the performance of the field they are serving. An easy approach to this problem is to have a few rappers assembled in the spare parts inventory for quick change-out when a malfunctioning rapper is found. When the malfunctioning rapper is disassembled and the defective component(s) replaced, the rebuilt rapper is then placed into the spare parts inventory.

The reasons for individual rapper failure depends on the rapper type. Magnetic-impulse, gravity-impact (MIGI) rappers may fail because of a short in the coil that lifts the rapper. Electric vibrators may fail because the proper air gap or sealing from the elements has not been maintained. Air-activated or pneumatic rappers often fail because water and/or oil enter the compressed air lines or because the solenoid fails to open the air supply line. Internal falling-hammer failures are more difficult to diagnose if the problems are inside the ESP. Problems such as misalignment of hammers with the anvils or a broken drive shaft usually cannot be diagnosed until the ESP is shut down for an internal inspection. Two of the more common problems with internal rappers are failure of the drive motor and failure of the gear reduction system.

Failure of the rappers serving one field of the ESP can usually be traced to the rapper control cabinet(s). Depending on the design, rapper controls are usually in separate cabinets for both the discharge electrodes and the collection plates. The collection plate controls may be further separated into individual cabinets for each field, or one cabinet may contain the controls for all the rappers on the ESP. If a failure at the control cabinet is the suspected cause for excessive dust buildup in the ESP, the first check should be to see if the power is on and that the fuse or circuit breaker has not been opened. A check should be made to ascertain proper operation of the switch and drive on some older systems that use rotary switches to activate the rappers. After these basic checks, corrective actions become more complicated and dependent on the rapper manufacturer. The manufacturer usually outlines specific procedures for testing the rapper control circuit boards for failed components. These are beyond the scope of this manual; however, some interesting problems have been noted, particularly with MIGI rappers. The most interesting problem is the continual failure of the rapper control card components. Failure or lack of a diode to protect the transistors from charges carried back to the rapper control cabinet may contribute to this failure. Most rappers are constructed with internal diodes for such protection, but not all of them. When no protection is provided for the cards, there is a potential for many card failures. Another problem involves the electrical arrangement of the rappers in such a manner that failure of one disables all of them. In some cases, this arrangement makes it nearly impossible to find the rapper that malfunctioned. Rappers wired in this manner should be rewired for ease of maintenance, i.e., in parallel instead of series.

When dust buildup is suspected and the rappers are in good operating order, the available options are to increase rapping frequency or to increase rapping intensity. Both options have certain advantages and disadvantages. Not all rapper control systems can control both frequency and intensity; however, if possible, an increase in rapping frequency is a good first choice (usually the only choice with internal rappers). Many dusts respond well to this, whether the buildup is caused by an increase in dust generation rate or an increase in resistivity. Rapping more frequently reduces the maximum dust layer thickness if sufficient rapping energy is provided.

If an increase in rapping frequency does not improve electrical characteristics after several hours, an increase in intensity may be required. Large increases in rapping energy should be avoided, however. Increases probably should not exceed 50 percent. Some ESP's are designed to withstand only limited rapping forces before damage to the ESP can occur. High-resistivity or sticky dusts usually require increased rapping intensity. If increasing rapping frequency and intensity fail to remove the dust (particularly high-resistivity dusts), a procedure called "power-off" rapping may help. Removing the power from the field to be rapped greatly diminishes the electric forces holding the dust to the plate and may allow the dust to be removed. Usually only one field at a time is rapped with the power off--for

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a period of 15 minutes to an hour. The power is usually turned off manually, although an automatic power-off option is available from some manufacturers on new T-R/rapper control systems. The disadvantage of this procedure is that it may increase the emissions from the ESP.

When all other measures fail to remove the material from the plates or discharge electrodes, the remaining option is to shut the ESP down and wash it out. This option should be kept at a minimum, as it may increase corrosion. Also, this can be an unpleasant task on cold January or February days. This procedure generally will remove the dust from the internal components; however, in some instances the dust layer must be scraped off, a time-consuming and difficult task.

All of the procedures discussed assume that the ESP has sufficient rapping capability, including appropriate rapping force, and that the design does not assign the cleaning of too much plate area to a single rapper. One aspect of the rigid-electrode or rigid-frame designs (of utility ESP's with large plates) that tends to overcome dust accumulation problems is the use of at least one internal rapper per plate. Two to four plates per rapper are the standard on smaller rigid-frame ESP's. In weighted-wire designs, the rapper may have to cover from two to six plates; however, the rapping intensity of these rappers is controllable. Additional rappers can be retrofitted to an ESP to reduce the plate area per rapper and to increase rapping effectiveness.

4.3.4 Corrective Actions for Wire Breakage

The general approach to correcting a wire breakage problem is to find the broken wire in the field and clip it out during the next convenient outage. Most of the time a broken wire is not replaced, and the bottle weight is removed to prevent its falling into the hopper. If wire failure is random, as many as 10 percent of the wires can be removed without significantly deteriorating ESP performance. Records should be kept of wire failure locations and dates to ascertain that they are indeed random.

If a pattern of failures begins to show, it should be interpreted as a symptom of some other problem. For example, a pattern showing that wires are failing in one area of the ESP or at the same location on the wire (top, bottom, middle, etc.) should alert plant personnel that the problems go beyond just a broken wire.

Several wire failure mechanisms were discussed earlier in this section. The most common is failure of the wire either at a plate/wire misalignment point or where the wire passes the edge of the plates in the collecting field (end effect). Localized corrosion due to inleakage may be reduced by reducing inleakage (sealing access doors, maintaining duct integrity). Crimping of the wires, which can cause excessive sparking or corrosion, may be a manufacturing and/or installation defect. In these instances, these wires may have to be replaced.

The problems with misalignment and end effects can be solved in various ways. When a misalignment problem is localized within an area of the ESP (e.g., because of three or four warped plates), plant personnel may opt to remove the wires in the gas lanes. This will usually improve operating voltages and current and prevent excessive wire breakage. This option should not be exercised unless the plates cannot be straightened. The danger of this procedure is that it may allow dust-laden gas to pass through the ESP essentially untreated if other adjacent upstream and downstream fields happen to be deenergized. To avoid this possibility, some plants weld plate steel into position to block the flow of gas down these lanes and force it to flow down other lanes. When the entire field is misaligned due to plate warpage or guide misalignment, clipping wires is not a sound solution.

Two methods are used to minimize excessive sparking due to end effects at the plates. The first is the use of wire shrouds that extend 6 to 18 inches from both ends of the wires. These shrouds are approximately 3/8 to 1/2 inch in diameter and generate corona only at very high operating voltages. In addition, it takes a long time for the spark to cause electrical erosion of the large effective wire diameter. The second method (designed into new ESP's) is the use of rounded plates at the top and bottom rather than sharp edges with an effective diameter equivalent to the plate thickness. In the new designs, the ends are rounded and approximately 2 to 3 inches in diameter. By reducing the distortion of the electrical field at the end of the plates, this new design reduces sparking. This latter change is difficult to retrofit into an existing ESP, but wires with shrouds can be used to replace most unshrouded wires and should be considered when wholesale wire replacement is scheduled.

When the 10 percent random wire failure rate has been reached or if more than 5 to 10 wires in any gas lane have been removed (depending upon ESP design), replacement of broken wires should be considered. This does not mean all the wires must be replaced. If the wire breakage rate appears to be on the increase, however, it may be advisable to replace all the wires. During replacement, care must be taken to avoid crossing wires and causing premature failure due to wear.

4.3.5 Corrective Actions for Hopper Pluggage

When hopper pluggage is detected, immediate action should be taken to clear the pluggage and empty the hopper. Maintenance personnel should give this problem highest priority, as failure to respond can significantly reduce long-term ESP performance.

Hopper pluggage can be caused by foreign objects such as wires or weights, cooling of the dust in the hopper or hopper throat, an undersized dust-conveying system, or the introduction of moisture into the hopper. Hoppers should be equipped with level detectors. They also should be insulated, and in many cases should be equipped with heaters. Rod-out capabilities are necessary, and a method of removing the hopper throat for emptying would be advantageous.

If a hopper is plugged but not filled, one appropriate action is to place the T-R controller for the field(s) above the plugged hopper in the manual mode to reduce the collection rate until the hopper is ready to be cleared. If the hopper is completely filled and the T-R has not tripped automatically, it should be turned off until the hopper has been cleared. The T-R must be deenergized while clearing of the hopper is in progress, to prevent electrocution of maintenance personnel. When ESP's are overdesigned in terms of sectionalization and plate area, their hoppers and dust removal system are often underdesigned. Because their inlet fields collect more material than was planned, the overload causes the hoppers to plug while the outlet fields remain virtually empty. When this occurs, the dust removal from the gas stream can be spread more evenly in the ESP by reducing power input to the fields that are plugged. This permanent reduction in power may change the pattern within the ESP and adversely affect its performance. The ESP must be adequately sized for this option to be exercised. (Note: Maldistribution of the gas stream can produce similar effects.)

The use of vibrators on the hopper does not necessarily enhance the flowing properties of all dusts. In fact, it can worsen the situation by compacting the dust in the hopper. Striking the hopper, however, can dislodge "bridges" of dust attached to the hopper walls. The hopper wall or throat should not be struck, as the impact may cause damage that provides a future site for hopper bridging and pluggage; rather, reinforced strike plates should be installed for the occasional strike that may be needed.

The use of hopper "stones" to fluidize the dust can provide mixed results. Placed near the bottom of the hopper, they may contribute to the pluggage problem by closing off open areas in the hopper. These stones, which are similar to those used to aerate aquariums, but much larger, must be supplied with dry, heated air. A high-quality dryer is needed to remove the moisture and oil, and the air must be heated so it will not cool the dust in the hoppers.

Excessive cooling of the dust can cause problems. Condensation of acid or moisture can solidify some dusts, make others extremely sticky, and simply cause some not to flow well. Hopper heaters and insulation usually help keep the hoppers warm. Pluggage of hoppers on the windward or north side of the ESP in the winter can cause excessive amounts of heat to be carried away from the hoppers. In many cases this can be corrected by constructing a windbreak or enclosing the hoppers to reduce cooling effects.

Finally, hoppers are usually sloped so as to provide good flowing characteristics. Gas sneakage baffles that project too far into the hopper sometimes contribute to the bridging problem. These baffles are desirable for preventing gas sneakage, and if bridging occurs, they can be shortened to minimize hopper pluggage.

If dust is suspected to have reached the plates and wires during an incident of hopper pluggage, a gas-load V-I curve should be generated to determine that no buildup, clinkers, or serious misalignment has occurred in the

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field(s). The T-R should then be returned to normal operation. When maintenance personnel clear the hoppers or open a hopper access door, care must be taken to avoid electrocution or being overcome by the dust or gas stream.

4.3.6 Corrective Actions for Misalignment

To perform the necessary work for correcting misalignment in the ESP requires an outage. Depending upon the extent of the misalignment, solutions range from simple application of heat and pressure to complete removal and replacement of the plates or discharge guide frames. As the repairs become more complex, the time required for correction also increases.

Failure of support, compression, or stand-off insulators for the discharge electrode system can cause widespread misalignment within the ESP between the wires and plates. Hopper pluggage can also shift the lower guide frame and contribute to the failure of standoff insulators. As indicated previously, reliable hopper level indicators are a means of avoiding misalignment due to hopper pluggage. The replacement of the insulators and subsequent realignment is relatively easy and straightforward if none of the internal ESP components have been bent.

Misalignment due to bent plates, bent wire, or bent rigid frames is more difficult to correct. If the point of misalignment is near the edge of the field, adequate access may be available to attempt corrective actions; however, misalignment that is halfway into the field, where access is poor, may be difficult to correct.

Plate straightening can be attempted by one of several methods. The simplest is to bend the plate back into shape by use of a small hydraulic press. Sometimes heating with a torch is alternated with water quenching to relieve the stress on the plate while returning it to position. Another option (for small sections of plate) is to remove the warped section with a cutting torch and replace it. (Note: Some plants merely cut away the warped section without replacing it, although this is poor practice.) This approach is generally limited to a section of plate edge small enough to fit through the access doors. Central portions of the plate area are generally not accessible. Care must be taken to remove all burrs and to smooth the plate before operation is begun again.

Some plants have tried replacement of plate sections or panels in ESP designs where the plate is composed of individual sections approximately 18 inches wide. In this time-consuming procedure, the plate sections to be removed are unclipped and detached from the plate hangers and guide. If enough room is available in the ESP for the panel and lifting equipment, the new panel or panels are brought in through the access door and the plate is reassembled. In major rebuilding involving replacement of large portions of plate area, it is often easier to remove the roof of the ESP and to replace the plates with a crane.

Bent wire frames or lower guide frames often cause the wires to slacken and bow towards the plates. Distorted lower guide frames are often difficult to straighten and may have to be replaced; however, if the distortion is not too severe and only a few wires are slack, it may be worthwhile just to remove those wires. On rigid-frame designs, space limitations often dictate the extent of straightening that can be done to the discharge frame. The wires may be tightened by crimping them *in the direction of gas flow*. This tightens the wires and prevents bowing towards the plate. It can also increase sparking and damage to the wire. Because the wires in rigid frame ESP's are usually of a larger diameter, however, it is usually an acceptable trade-off.

In summary, if a general misalignment is caused by a shift in guide frame components, it usually can be corrected by realigning the frame. Plate warpage or wire frame warpage may be more difficult to correct, however. All ESP's have a certain freedom of motion to allow expansion and contraction. Checks should be made to see that this freedom is maintained and that there is no binding before the other approaches to correcting misalignment are considered.

4.3.7 Corrective Actions for Inleakage

The corrective action for inleakage is straightforward. Unless the design calls for the admission of ambient air for a specific purpose, any spot of inleakage should be sealed. Such an approach reduces the total gas volume to the ESP's, can help to prevent acid dewpoint problems, contributes to more stable operation, and can enhance the gas distribution into the ESP.

All access doors should remain sealed during routine operation. This includes hopper access doors and penthouse doors. On newer designs, the use of double doors for sealing and insulating has become popular to minimize inleakage and door corrosion. Gaskets should be checked periodically and replaced if damaged. Any corrosion around doors or expansion joints should be corrected immediately, as the corrosion rate tends to accelerate around these points.

A routine check of oxygen content and temperature in combustion flue gas is a useful indicator of inleakage. Such checks should be conducted along the ductwork from the process exit to the ESP outlet. (Note: A system under positive pressure generally does not have inleakage problems, but outleakage may contribute to fugitive emissions and exterior corrosion.) Any sudden increase in O_2 in a nonstratified gas stream indicates inleakage. This is usually accompanied by a corresponding decrease in temperature. The point of inleakage will usually be between the sampling locations where the change in O_2 occurred. The causes can be a broken or worn seal, a hole in the ductwork, or sampling ports that someone left open. Appropriate action should be taken.

4.3.8 Summary

Because problems are often site- and design-specific, extensive coverage of corrective action is not possible. Nevertheless, the major problems have been addressed. As previously stated, it is useful to understand the nature and magnitude of the effects of various ESP problems. Before selecting any corrective action, one must first determine the cause of the problem so that the proper corrective action is chosen rather than one that merely treats the symptom. Long-term ESP performance usually benefits from this approach.

REFERENCES FOR SECTION 4

1. McDonald, J. R. and A. H. Dean. A Manual For the Use of Electrostatic Precipitators to Collect Fly Ash Particles. EPA-600/8-80-025. May 1980.

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SECTION 5
O&M PRACTICES

5.1 OPERATING PRACTICES

Operating practices can significantly affect daily and long-term ESP performance. Because they are site specific, only the most general of practices can be presented here, and their characteristics must be considered in the establishment of operating practices and procedures. These practices and procedures should be straightforward and cover most of the situations expected to be encountered, and personnel should be trained so that these practices become routine.

5.1.1 Startup Practices

Startup practices greatly affect the subsequent operation of an ESP and may be as important to performance as daily operating checks and maintenance practices. Major concerns during the startup of ESP's on most processes are corrosion and buildup of material on plates, wires, and insulators, which can severely limit ESP performance. For some processes, the potential hazard of fire and explosion resulting from unstable operations is a primary concern. Startup practices should be geared to address these potential problems.

Personnel safety should be the foremost consideration in any startup procedure. Before anyone enters an ESP for inspection or maintenance, ground devices should be installed to be certain that all built-up charge is discharged and that T-R sets are disabled and main breakers are locked out so they pose no threat to personnel. When preparing for startup of the ESP, these safety devices must be removed so that the T-R can operate. One person or small group of persons should be responsible for checking the ESP to

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ascertain that it has been cleared of all personnel, tools, parts, and other miscellaneous materials and that the scheduled maintenance has been completed. For the sake of discussion, let us assume that an inspection for maintenance, alignment, etc. is performed separately. When the check for clearance of personnel, tools, and equipment has been completed, the ESP should be closed up and locked by use of a safety key interlock system. When several persons are involved in the final checkout for startup, the responsibilities of each person or group should be clearly outlined. Checklists are useful reminders for the individual items to be checked and serve later as written reference that specific items have been checked.

When the ESP has been closed up and the keys for the interlock system have been returned to their appropriate locations, an air-load test should be run for each T-R set and, if time permits, for each bus section to ascertain that all maintenance has been completed, all foreign matter removed, and that the ESP is ready for operation. The air-load test is conducted under ambient conditions with little or no air flow during energization of each section. The test result should be an air-load curve for each T-R, which should become part of the permanent record for the unit. Points of interest are the voltage at corona initiation, the shape of the voltage/current curve, and the voltage and current values when sparking occurs. The preferred readings are secondary voltage and secondary current, but primary voltage and primary current may be used. When secondary voltage meters are not available, primary voltage versus secondary current is sometimes used. The voltage and current should be increased gradually until sparking occurs. If sparking does not occur, the power should be increased until the current limit is reached. (Note: The voltage limit is rarely reached.)

For fields of similar geometry (same T-R capacity, same wires, wire-to-plate spacing, ft^2/T-R, etc.), the V-I curves that are generated should be similar. Slight differences may occur because of internal alignment or buildups, but generally each curve should be nearly identical under air-load conditions. Any major deviation between the curves or between a curve and a reference curve (when the unit was new) may indicate an internal problem. Spotting a problem from these curves may afford the opportunity to correct

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that problem before startup. This procedure also provides a final check that the scheduled maintenance was performed during the ESP shutdown.

The symptoms of various problems are shown in Section 4. The air-load test curves will differ from gas-load conditions, when operating temperatures and particulate cause the curves to shift. Any similarity between air-load and gas-load curves is coincidental.

Insulator heaters and hopper heaters should be turned on 2 to 12 hours prior to startup. Purge-air systems also should be activated at this time. Because environmental regulations generally do not allow bypass of the control system during startup, some portion of the system must be in service. Condensation should be minimized in these areas to prevent insulator leakage or tracking and to prevent pluggage of hoppers at startup.

Even if the ESP is not energized, the rapping system and hopper evacuation system should be in operation during startup to remove any dust that has settled. Because gas loads and particulate loadings are much below normal operating loads, the ESP can be an effective settling chamber and remove the large-diameter particulates entering it. An increase in rapping intensity is normally suggested to dislodge any wet (from condensation) or sticky particulate that has collected on the wires and plates to prevent buildup problems from affecting performance as full load conditions are approached. Rapping intensity can then be returned to normal after operating temperature is reached.

When and how much of the ESP should be energized is a much-debated topic in many applications. Many believe that energization should not be attempted until the moisture dewpoint has been exceeded for several hours, and some like to wait until the acid dewpoint temperature has been surpassed, to avoid excessive sparking and to minimize buildup on the ESP internals. Newer, modern, power supplies, however, should be able to energize the ESP with little or no sparking, whereas older controllers probably should be set in manual control below the spark threshold. The concern with sticky particulate and sparking is two-fold. At best, if the sticky particles fuse or clinker on the plates and wires, the ESP will have to be shut down and washed out. At worst, unstable combustion could lead to unburned carbon, hydrocarbons, and

CO in the ESP, which may be set afire or result in an explosion that endangers personnel and could also permanently destroy the ESP's performance potential. Substantial misalignment can occur within an ESP as a result of a fire or explosion. Because of the tendency for an ESP to spark during startup and provide a possible ignition source, some plants have approached the explosion potential by lengthening their startup times. For example, in some cement kiln applications, startup times of up to 12 hours are not uncommon to avoid CO explosions that may be caused by unstable operation during startup. It is ironic that the monitors used to detect CO or combustibles and deenergize the ESP to prevent explosions or fire are so slow in detecting a "spike" that by the time the danger is monitored the combustible mixture has passed through the ESP. If ignited by a spark, the resulting fire or explosion is noted by the continuous monitor from 15 seconds to 2½ minutes after the fact and merely serves as an epitaph to the damaged ESP.

Energizing the entire ESP during startup is usually unnecessary; only enough of the ESP should be energized to maintain emissions below opacity limitations. This means that the ESP is brought on line stepwise; the number of T-R's energized is increased as particulate and gas load increase. Recommendations vary as to which fields should be energized first. Usually either inlet or outlet fields are recommended for initial energization, and there are good arguments for either approach. The argument for inlet field energization is based on the fact that scouring action on the wires and plates tends to occur when loads are increased; because these fields experience the heaviest loading at full capacity, any deterioration of performance due to buildup of particulate will be minimized. The argument for outlet field energization is that the cleaning action of the heavier particulate may never occur and that these charged and collected undesirable particles can penetrate into the second (and possibly third) field and cause unsatisfactory performance of the ESP. If fouling occurs in the ESP, it occurs in the outlet field, whose function is usually the final cleanup of rapping emissions and fine particle capture, and this field is less crucial to mass removal than are the inlet and second fields. This is a version of controlled damage

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potential. It is further argued that damage due to fire or explosion is confined to one field. This may be true for fire potential, but not necessarily for an explosive condition.

As the process load and gas temperature increase, more of the ESP is energized and higher power levels may be achievable. Some manufacturers have controllers which automatically increase power levels based on opacity readings. As full load is approached, the entire ESP should be energized, placed in automatic control, and optimized for power input and spark rate. After several hours of stable operation, rapper intensity should be set back to normal levels.

5.1.2 Routine Operation

During routine daily operations, some variations will occur in operating voltages and currents, depending on dust characteristics and process operations. Unless variations are extreme, daily requirements include parameter monitoring and recordkeeping, preventive maintenance, evaluation for malfunctions, and response to malfunctions. If no problems arose during startup, performance should be governed by daily operations. (Parameter monitoring, recordkeeping, and evaluation for malfunctions were discussed in Sections 3 and 4, and preventive maintenance will be discussed in Section 5.2.)

Response to malfunctions is important in avoiding deteriorating performance and possible damage to the ESP. These malfunctions have a tendency to cascade and build upon themselves. For example, a broken wire can cause deterioration of ESP performance in a roundabout way. The broken wire may result in a T-R trip and a weight or wire in the hopper, which may in turn plug the hopper. This allows dust to build up, which warps plates and misaligns wire guide frames, and ultimately results in diminished ESP performance even after the T-R operation is restored. Routine checks of voltage and current levels, rapper operation, dust removal, opacity, and process operation are necessary to catch problems early.

Some operations experience gradual deterioration in performance, usually due to resistivity problems, but the generation of sticky particulate can also limit performance. One approach to this problem is to try to optimize

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ESP performance and to make changes in the process feed or operation. This may include conditioning of or restrictions on process materials to prevent the generation of the particulate that causes this degradation with time. Another approach is to allow the performance to degrade and schedule periodic washdowns of the ESP. Some combination of both procedures may be applicable, wherein some conditioning or restriction of fuels or process materials slows the performance degradation and allows scheduled shutdowns to be more widely spaced. This latter approach generally requires more careful monitoring to avoid rapid and uncontrollable degradation.

5.1.3 Shutdown Practices

Except for emergency shutdown procedures, the process should be essentially the reverse of startup procedures, but much simpler. As process load decreases, the ESP generally can be deenergized one field at a time. As in startup, the selection of the first field to be deenergized is a site-specific decision; however, deenergization of the inlet fields is usually favored. As each field is deenergized the electrical field that held the dust to the plates is released. Having the next field in line energized reduces the quantity of emissions. In addition, the reduction in particulate load will reduce the quantity of material on the plates. Again, higher than normal emissions may be allowed during shutdown, but the extent of the emissions should be reduced insofar as possible.

When the process is shut down, all remaining T-R's should be deenergized. Again, sequential deenergization toward the outlet is preferred, but it should be done relatively quickly to prevent unnecessary sparking, condensation, or insulator buildup. The rappers and hopper evacuation system should be allowed to run anywhere from several hours up to 24 hours to remove as much dust as possible from the ESP. (Under special circumstances, rapper operation may be terminated at shutdown to retain dust on the plates so patterns of buildup can be observed during a subsequent internal inspection and washdown; however, because turning off the T-R's will affect these patterns, little may be gained from turning the rappers off.) Note: Shutdown procedures can have a bearing both on the maintenance required during the outage and on the success of the next startup.

In general, shutdowns are better controlled and present less problems than startups do, primarily because the equipment is warm and has been under relatively stable operation. In the case of an emergency shutdown, however, one practice is almost universal--the entire ESP is tripped off line. Emergency conditions may include anything from a fuel feed problem in a cement kiln or boiler that presents a potential fire or explosion hazard to a ruptured tube in a boiler or a turbine trip that takes the boiler off line. Under some circumstances, the ESP power supplies are interlocked to these systems rather than relying on a monitor to measure possible combustible or explosive conditions in the gas stream. The sudden release of emissions due to deenergization can be substantial and, in some cases, in excess of normal operating emissions for the rest of the year; however, this may be necessary to avoid expensive repairs and excessive downtime. Some consideration should be given to both the short- and long-term effects. Overreaction to a problem is not a solution. For example, rupturing of waterwall or economizer tubes usually calls for immediate deenergizing of the ESP even though the increased water in the gas stream may improve performance dramatically. If the dust is not removed from the ESP immediately, the usual highly undesirable result is mud in the ESP. On the other hand, failure of the tubes in the superheater or reheater area of a boiler may not necessitate immediate and complete deenergization of the ESP, even though the boiler is tripped out of service rather quickly. Again, the reader is reminded of the cement application, where the current generation of the monitors is probably inadequate to protect against a fire or explosion.

If a fire or explosion does occur, the ESP should be deenergized. Although a certain amount of damage has probably already been done, deenergizing may help to contain the damage. Fires should be allowed to burn out by themselves, but in the case of a hopper fire, the hopper should be emptied through the ash conveying system. The hopper door should never be opened, and water or steam should never be used to put out a fire. The inrush of air may increase the burning rate or set up an explosive mixture, and under certain circumstances water can be reduced to hydrogen, which increases the explosive potential.

5.2 PREVENTIVE MAINTENANCE

The goal of preventive maintenance is to maintain the long-term performance of the ESP and to reduce or minimize the failure of various components that affect ESP performance. An important aspect of preventive maintenance is routine inspection of the ESP, both internally and externally. These inspections include daily or shift inspections, weekly inspections, monthly or quarterly inspections, and outage inspections (the only time internal inspections can be performed). Depending on the unit's operating history and the manufacturer's recommendations, internal inspections can be performed quarterly, semiannually, or annually. As the time interval increases, the amount of action required usually increases. Daily and weekly inspections may require checks of operating parameters and general operating conditions, whereas monthly or quarterly inspections require specific actions regardless of performance of the ESP.

5.2.1 Daily Inspection and Maintenance

Most often the daily inspection or shift inspection will be conducted as part of a parameter monitoring and recordkeeping plan. The purpose of this routine and frequent inspection is to identify the existence of any operating problems before they develop into more serious and possibly more damaging failures. It is extremely important to have all ancillary equipment equipped with alarms, and plant personnel should respond to these alarms immediately. As has been discussed in Section 4, some problems can and have led to long-term degradation of ESP performance because they failed to be diagnosed or no action was taken to correct them.

The instrumentation available for most ESP's provides the first indicator of performance problems. Process operating data and ESP corona power levels should be recorded and compared against baseline values or normal values established for the source. The corona power values may be obtained from primary voltage, primary current, secondary voltage, and secondary current levels for each field in the ESP. In most applications, opacity values also may provide an indication of ESP performance. Although most regulations require the data to be reported on the basis of integrated 6-minute averages, the ability to observe the magnitude and frequency of individual rapping spikes is beneficial in optimizing ESP performance. Any changes in these values, either from previous normal readings or baseline conditions, are important because they may indicate the need for further investigation and/or maintenance.

Once the readings have been obtained and checked for any apparent changes, some simple external checks are in order. If the operating values of a field or fields show considerable change, the remainder of the inspection should concentrate on attempting to identify the cause of the observed changes. The electrical readings should identify at least one and possibly more of the potential causes for the change. In addition to the electrical readings, the following items also should be reviewed.

The operation of the dust discharge system should be checked. All conveyors, airlocks, valves, and other associated equipment should be operating for continuous removal of the collected dust. If hopper heaters are necessary to maintain the hopper temperature, the current levels at each hopper will indicate whether these heaters are operating. Hopper throats should be warm to the touch; a cold hopper throat may indicate that the hopper is plugged. If a vacuum system is used, vacuum charts may provide a useful indication of proper hopper emptying. Of course, the operation of indicator lights on hopper level alarm systems also should be checked. While in the hopper area, the one performing the inspection should check all access doors for audible inleakage or dust discharge.

The operation of the rappers should be checked. This may be difficult on some systems because of the delay times between rapping cycles and a "maintenance-check" mode. Although it is not necessary to check the operation of every rapper, almost every rapper should activate. The purpose of this check is to determine if the entire field or the entire ESP rapping system is out of service. If possible, individual rappers that are not operating should be identified so that appropriate maintenance may be performed. If monitored, the frequency and intensity of rapping also should be noted.

Other checks of the ESP externals include sparking or arcing in the T-R high-voltage bus duct, localized sparking (usually reflected by T-R readings), and audible inleakage around all other access hatches on the ESP.

Although these problems will generally affect ESP performance, if they are corrected in a timely manner, the effect will not be long-term. Figure 5-1 summarizes the data that the operator or ESP coordinator should record daily.

5.2.2 Weekly Inspection and Maintenance

The best way to start a weekly inspection is with a brief review of the daily or shift inspection data. This review should attempt to identify any apparent trends in the key operating parameters and to determine whether a change is needed in some operating practice or maintenance procedure. In addition, this review should confirm that all requested or required maintenance has been completed satisfactorily or has been scheduled in a timely manner. Lastly, a week is generally sufficient time for a change in operation (e.g., rapping intensity and timing, some process changes, gas-conditioning systems operation) to surface in ESP performance, even though longer periods may be necessary to establish the trend.

After reviewing the previous week's operating data and comparing it against normal or baseline values, the inspector should make a physical check of the ESP, including daily or shift inspection activities. The items covered in the following paragraphs also should be checked.

When the T-R readings are obtained, the cabinet air filters should be checked and cleaned or replaced. Although some cabinets may not be equipped with cooling fans, the air intakes and vents should be filtered to keep the cabinet internals clean. Dust buildup on circuit boards and heat sinks can cause excessive heat buildup and electrical problems within the control circuitry. It is generally recommended that T-R control cabinets be placed in a temperature-controlled, clean environment to minimize failure of controller circuitry. Integrated circuits cannot withstand the high temperatures that may accompany a hot, dirty environment.

Rapper operation should be checked more thoroughly during the weekly inspection. Each rapper or rapper system should activate, and those that do not should be scheduled for repair or replacement. Proper operation of internal falling-hammer systems is more difficult to ascertain, but rapper drive motors should operate when activated by the rapper controller. If

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DAILY INSPECTION CHECKLIST

- Corona power levels (i.e., primary current, primary voltage, secondary current, secondary voltage) by field and chamber. (twice a shift)
- Process operating conditions [i.e., firing rates, steam (lb/h), flue gas temperature, flue gas oxygen, etc.]. The normal operator's log may serve this purpose. (hourly)
- Rapper conditions (i.e., rappers out, rapper sequence, rapper intensity, rapping frequency by field and chamber. (once a day)
- Dust discharge system (conveyors, air locks, valves for proper operation, hopper levels, wet-bottom liquor levels.
- Opacity (i.e., absolute value of current 6-minute average and range or magnitude of rapper spiking) for each chamber duct if feasible. (2-hour intervals)
- Abnormal operating conditions (i.e., bus duct arcing, T-R set control problems, T-R set trips excessive sparking). (twice a shift)
- Audible air inleakage (i.e., location and severity). (once a day)

Figure 5-1. Items that the operator or ESP coordinator should record daily.

rapper settings are provided (i.e., rapping intensity, duration, and frequency), these should be recorded. Changes in rapper operation should be made as necessary or desired for optimum operating characteristics. The new settings should also be recorded, and the performance should be assessed during the next week of operation.

While on the roof of the ESP, the inspector should note the operating temperature and oil level in the high-voltage transformer. Generally, indicators on the transformer will show the desired operating range. In addition, the operation of any insulator purge air and heating systems should be checked. Air filters on the purge air system should be checked and cleaned or replaced. Failure of the purge air system may cause fouling or condensation on insulator surfaces, which can result in electrical tracking or breakage of the insulator. In negative pressure systems, if insulators can be contaminated by variations in the ID fan operation or during startups, the insulator pressurization and heating system should be checked more often.

All access hatches should be checked for inleakage, both by listening and feeling around the hatch. The hatch should be fully closed and locked. If inleakage occurs, the door gasket (or possibly the door) should be replaced. Inleakage can cause excessive sparking in localized areas, corrosion, reentrainment of particulates, and wire breakage due to reduced temperatures. Figure 5-2 summarizes the items that the operator or ESP coordinator should record weekly.

5.2.3 Monthly to Quarterly Inspections and Maintenance

Whether a monthly or quarterly inspection is required depends on the manufacturer's recommendations and on selected site-specific criteria; however, all of the recommended procedures should be followed at least quarterly.

The control cabinets for T-R sets and rappers should be cleaned (vacuumed) to remove any accumulated dust and dirt inside the cabinet. The exterior of the cabinets for rapper controls should be checked for proper seal of the door gaskets. If allowed to deteriorate, these gaskets will permit water and dust to enter the cabinet and may result in failure of the rapper control cabinet. In addition, all switch contacts within the rapper control cabinet should be cleaned.

WEEKLY INSPECTION CHECKLIST

- Trends analysis (plot gas load V-I curves for each field and chamber and other key parameters to check for changes in values as compared with baseline).
- Check and clean or replace T-R set cabinet air filters and insulator purge air and heating system filters.
- Audible air inleakage (i.e., location and severity).
- Abnormal conditions (i.e., bus duct arcing, penthouse and shell heat systems, insulator heaters, T-R set oil levels, and temperature).
- Flue gas conditions exiting the ESP (i.e., temperature and oxygen content).
- More extensive rapper checks (also optimize rapper operation if needed).

Figure 5-2. Items that the operator or ESP coordinator should record weekly.

All rappers should be checked for proper operation. Checks should include proper striking of anvils for MIGI rappers, proper lift, and energy transfer. Pneumatic systems and vibrators should be adjusted as necessary to transfer the proper amount of rapping energy to the collection or discharge systems. Although ESP's equipped with falling-hammer rappers are more difficult to check, gear-reduction drive systems should be checked for proper sealing. The boots may fail over a period of time and allow water and cool air to enter the ESP. This can cause local corrosion or ESP operating problems due to inleakage.

Hopper heaters should be checked for proper operation if the ESP is so equipped. As previously mentioned, the purpose of these heaters is to help the dust stay warm and permit it to flow smoothly. Hopper-level alarm systems should be checked for proper operation.

The ESP's instrumentation should be checked and calibrated. This includes all voltage and current meters. The primary voltage and current meters should be calibrated as AC RMS values, whereas the secondary voltage and current meters should be calibrated against a DC power supply. The transmissometer should also be cleaned and realigned during this inspection. Figure 5-3 summarizes the items that the operator or ESP coordinator should record quarterly.

5.2.4 Semiannual Inspection and Maintenance

Depending on the operation, the semiannual inspection may correspond with a maintenance shutdown or outage, and internal inspections are conducted, during such outages. Considerations for an internal inspection are discussed under the Annual Inspection subsection.

In addition to the recommended procedures for quarterly and weekly inspection and maintenance, semiannual procedures should include the lubrication of all door hinges and closure mechanisms, the cleaning and lubrication (with graphite) of key interlocks, and a check of all ground connections [grounding straps and sampling and testing transformer oil for maintenance of dielectric strength (insulating capability)].

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QUARTERLY INSPECTION CHECKLIST

- Internal inspection of shell for corrosion (i.e., doors, hatches, insulator housings, wet-bottom liquor level, dry bottom, roof area).
- Effectiveness of rapping (i.e., buildup of dust on discharge electrodes and plates).
- Gas distribution (i.e., buildup of dust on distribution plates and turning vanes).
- Dust accumulation (i.e., buildup of dust on shell and support members that could result in grounds or promote advanced corrosion).
- Major misalignment of plates (i.e., visual check of plate alignment).
- Rapper, vibrator, and T-R control cabinets (motors, lubrication, etc.).
- Rapper distribution switch contacts (i.e., wear arcing, etc.) that are now used infrequently.
- Vibrator cam contacts (i.e., wear, arcing, etc.) that are no longer used.
- Rapper assembly (i.e., loose bolts, ground wires, water in air lines, solenoids, etc.).
- Vibrator and rapper seals (i.e., air inleakage, wear, deterioration).
- T-R set controllers (i.e., low-voltage trip point, over-current trip point, spark rate, etc.).
- Vibrator air pressure settings.

Figure 5-3. Items that the ESP coordinator should record quarterly.

5.2.5 Annual Inspection (Outage) and Maintenance

The process and its ESP generally should be shut down at least once a year for a more complete inspection, including a check of internal conditions. The design of some ESP's is such that they may be isolated or bypassed without a process shutdown. In other situations, however, outages may occur on a more frequent basis. In all cases, however, adherence to established safety and confined-area entry procedures cannot be overemphasized. Safety interlocks should never be bypassed to enter the ESP.

Before anyone enters an ESP, an air-load check of each field is recommended. This serves as a record for comparison when the ESP maintenance is complete and all scheduled maintenance has been performed. When these air-load tests have been completed, the inspection is ready to begin (Note: gas-load tests may be used just prior to shutdown). During the inspection more attention may be focused on certain selected areas where readings are abnormal or unusual.

With the key interlock system, the actual opening of the ESP can be a relatively time-consuming operation; however, this system provides a method of locking out and grounding the power supply to prevent accidental energization while personnel are inside. In older ESP's, hopper systems were generally excluded from the key interlock system, but most new systems include the hopper access doors in the system.

When the key interlock system procedures have been completed and the doors opened, the grounding straps should be attached to a wire inside the access door. This establishes a positive ground to bleed away any voltage retained by the plates (the ESP behaves like a large capacitor) and to prevent energization of a field if, for some unforeseen reason, the interlock system should fail. These grounding straps are recommended for each field in the ESP.

Before anyone enters the unit, the confined work area should be sampled and evaluated for oxygen deficiencies and the presence of toxic substances and combustible materials. It is generally recommended that the ESP be cooled and purged prior to entry; however, with proper safety equipment and precautions, inspections can be performed without this extra step. Routine

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monitoring of internal conditions should be part of the safety plan, but continuous personal monitors with alarms are preferred. The point of initial entry into the ESP will depend on access and maintenance considerations. For the purpose of this section, entry is assumed to be through the side of the ESP at the bottom of the plates.

The initial inspection of a collecting and discharge electrode system should be used to observe several items. The first is whether there is a buildup of material on the surfaces. Generally, 1/8 to 1/4 inch of material will remain on the plate even in its clean, "rapped-down" condition. Too much buildup can lead to both energization and gas distribution problems within the ESP and is indicative of poor or ineffective rapping. Clean metal conditions may indicate low resistivity, high gas velocity, or too much rapping. Buildup on wires should be minimal.

The nature, extent, and locations of any buildups within the ESP should be noted. While checking for buildups, the alignment of the wires and plates also should be checked. Any bowing or skewing of the alignment of more than ± 1/2 inch is usually visible, and its location should be noted for corrective action. This check is conducted for each lane of each field within the ESP. A misaligned ESP usually causes reduced voltage and power input and increased sparking.

Checks for broken wires are usually conducted in fields where short-circuits are found. The broken wires should be clipped and removed, as should the bottle weight. The location of the broken wire and where the wire failed should be recorded as part of the permanent record. Generally, wires are not replaced individually as they fail because the performance of the ESP does not suffer greatly if several wires are missing as long as the wire failures are random. On the other hand, failure in the same location generally indicates a problem. Wires also should be the proper length. It is not unusual for individuals to cross wires to shorten them so they will fit within the upper and lower guide frame; however, the rubbing of the crossed wires during operation will cause wire failure.

The upper and lower discharge guide frame assembly should be aligned so that equal spacing is maintained, not only from the top to the bottom of the

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plate, but also from the leading edge to the trailing edge of the plates. The frames should be level in both parallel and perpendicular planes to the gas flow. Frames that are not level or twisted frames may cause excessive tension on some wires and insufficient tension on others (slack wires). When checking the upper discharge frame, the upper support beams should be checked for excessive dust buildup. These buildups will sometimes cause intermittent high sparking in the upper section of the ESP, which reduces collection efficiency. Additional baffles may be necessary to prevent such dust buildups.

All insulators should be checked and cleaned to remove dust accumulation. They should also be checked for any evidence of insulator tracking. The inspection should include both the inside of the large support bushing insulators at the top of the ESP and the discharge rapper insulators. Any insulators that are broken, chipped, cracked, or glaze-damaged should be removed and replaced.

Hoppers should be emptied during shutdown. Some buildup may be found in the corners or in the upper portion where the hopper joins the ESP housing, and these buildups should be removed. In flat-bottom ESP's in recovery boiler applications, the space between agitators should be checked and any buildups should be removed. All hopper level detectors should be checked and repaired as necessary, and defective hopper heaters should be replaced. Since nuclear hopper level detectors can expose maintenance personnel to radiation, the built-in shields should be put in place before any personnel enter the hopper. All dust discharge valves should be checked and cleaned and repaired as necessary. These valves should be maintained to prevent any inleakage of air into the hopper, which can aggravate hopper pluggage and cause dust reentrainment.

The interior of the ESP should be inspected for corrosion of the shell, plates, and wires. Localized areas of corrosion may indicate points of inleakage, which cause temperatures to fall below the acid dewpoint. Sonic testing can be utilized to determine the thickness of the shell. Besides reducing the strength of materials, corrosion can cause scaling of the metal components, which interferes with the clearances within the ESP and reduces performance. Corrosion and excessive dust in the penthouse or insulator

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housing may indicate that insufficient purge air is being supplied to the insulator housing, which will cause condensation of flue gas in this area.

Rapper rod connections or anvils for the discharge system and the plates should be checked. Loose, broken, or bent connections should be repaired to allow rapping force to be transferred efficiently into the ESP. Failure of the rapper rods may not be evident from dust buildup on the plates and wires if sufficient force is still being applied.

The T-R's should be checked and cleaned during shutdown. All contacts should be removed, cleaned, and adjusted. All electrical connections should be checked for proper tightness. Loose connections and dirty contacts can cause electrical erosion and wasted energy, and may lead to failure of the T-R. The high voltage line, bushings, and insulators should be checked and cleaned. Surge arrestors should be checked and replaced if necessary. The high-voltage bus duct should be checked for dust buildup and corrosion, which could lead to grounding of the transformer secondary. All leaks in the bus duct should be repaired during the reassembly to keep moisture and inleakage to a minimum. All insulators contained within the bus duct should be checked and cleaned or replaced as necessary. All insulators which are chipped, cracked, or damaged with glaze due to electrical tracking should be replaced. Tightness of the connections for the high-voltage bus duct should be checked. Transformer switchgear should be cleaned and adjusted for proper contact.

Some general areas requiring attention during the annual outage include a check of door gaskets for proper seal. It may be worthwhile to replace these gaskets annually or biannually to minimize inleakage. Another area is the inlet and outlet distribution system, which should be checked for pluggage and dust buildup. This includes the inlet and outlet ductwork. Buildups that result in poor gas and dust distribution within the ESP should be removed. If the buildups are substantial and recurrent, some modification may be needed to minimize them. Expansion joint seals should be checked for integrity and replaced if necessary. Failure of expansion joints can lead to excessive inleakage and increased corrosion. Lastly, water washdown of the ESP is generally not recommended unless a dust is present that will adversely affect ESP performance after startup and there is no other way of removing

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the material from the plates. Water-washing an ESP can accelerate corrosion and cause rust and scaling, which interfere with the electrical performance of the ESP; therefore, the ESP must be dry before operations resume. Figure 5-4 summarizes the items that the operator or ESP coordinator should check during the annual outage inspection.

At the completion of the outage, all personnel, tools, and other materials used inside the ESP should be accounted for. A final safety check should be completed for each section of the ESP to determine that all personnel have exited before the ESP is closed up. An air-load test of each field should then be performed. This final air-load test will indicate whether the scheduled maintenance was in fact completed. The air-load test will also detect any mistakes or forgotten items and will serve as a record or certification of readiness for operation. This air-load test should also become part of the permanent records kept by the plant maintenance personnel.

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ANNUAL INSPECTION CHECKLIST

- Transformer Enclosure

  HV line, insulators, bushings, and terminals
  Electrical connections
  Broken surge arrestors

- High-Voltage Bus Duct

  Corrosion of duct
  Wall and post insulators
  Electrical connections

- Penthouse, Rappers, Vibrators

  Upper rapper rod alignment
  Rapper rod insulators
  Ash accumulation
  Insulator clamps
  Lower rapper rod alignment
  Support insulator heaters
  Dust in penthouse area
  Corrosion in penthouse area
  Water inleakage
  HV connections
  HV support insulators
  Rapper rod insulator alignment

- Collecting Surface Anvil Beam

  Hanger rods
  Ash buildup
  Weld between anvil beam and lower rapper rod

- Upper Discharge Electrode Frame Assembly

  Welds between hanger pipe and hanger frame
  Discharge frame support bolts
  Support beam welds
  Upper frame levelness and alignment to gas stream

- Lower Discharge Electrode Frame Assembly

  Weight guide rings
  Levelness of frame
  Distortion of the frame

Figure 5-4. Items that the operator or ESP coordinator should check annually. (continued)

- Stabilization Insulators
  - Dust buildup and electrical tracking
  - Broken insulators
- Collecting Electrodes
  - Dust deposits; location and amount
  - Plate alignment
  - Plate plumbness
  - Plate warpage
- Discharge Electrode Assembly
  - Location of dust buildup and amount
  - Broken wires
  - Wire alignment
  - Weight alignment and movement
- Hoppers
  - Dust buildup
  - Level detectors
  - Heaters
  - Vibrators
  - Chain wear, tightness, and alignment
  - Dust buildup in corners and walls
- Dust Discharge System
  - Condition of valves, air locks, conveyors
- General
  - Corrosion
  - Interlocks
  - Ground system
  - Turning vanes, distribution plates, and ductwork

Figure 5-4 (continued)

SECTION 6
INSPECTION METHODS AND PROCEDURES

This section presents detailed techniques and procedures for conducting the following inspections of ESP systems and associated components: preconstruction and construction inspections; external inspections; internal inspections; special inspections and observations that should be made with respect to air-load and gas-load tests, baselining, and performance tests. Safety considerations during inspections are presented, and the use of portable instruments and safety equipment is discussed.

The purpose of any ESP inspection is to determine the current operating status and to detect deviations that may reduce performance or cause failure at some future date. For this reason, inspection programs must be designed to derive maximum benefit from the information gathered during the inspection.

A properly designed inspection program can be used for three purposes: recordkeeping, preventive maintenance, and diagnostic analysis. Depending on its purpose, the inspection may be conducted by operators, maintenance staff, regulatory agency inspectors, outside consultants, or vendor representatives.

The external ESP inspection (on-line) usually is limited in scope to critical components. Checks of the operating status of the unit are limited to gas volume, general operating characteristics (moisture, temperature, oxygen, SO_2, etc.), rapper function, dust removal system function, insulator temperature/heater function, electrical readings, and process conditions. From this information, internal conditions and emission rates may be inferred and/or calculated.

The internal inspection provides information on corrosion, alignment, insulation condition, points of air inleakage, effectiveness of rapper function, and distribution plate pluggage.

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Taken together, internal and external inspections provide continuous information to aid in the operation and maintenance of the unit.

6.1 PRECONSTRUCTION AND CONSTRUCTION INSPECTIONS

Preconstruction inspections are necessary to ensure that the correct ESP components and structural members are received and properly stored for subsequent assembly. Many of the later O&M problems with an ESP can be traced to improper design, fabrication, and storage of critical components. This section provides guidance for establishing a preconstruction/construction acceptance program that will help to reduce subsequent maintenance problems that are related to poor project planning, and management and unit construction. Table 6-1 presents an example of an ESP erection sequence. Each manufacturer has its his own sequence; this one is provided for illustrative purposes only.

6.1.1 Plans and Specifications

Many maintenance problems are created during the critical period of initial design. The special limitations and conditions placed on the unit by the specific process application must be considered. Design of the shell must meet site-specific constraints such as adjacent structures, crane movement, overhead clearances, and stack conditions. In this early design stage, O&M personnel must be involved to define projected O&M requirements. A thorough review of each component, subassembly, and structure is critical. Many designs that appear to be adequate on paper and to meet all safety requirements cannot be properly maintained after they are built.

A list should be prepared of all known or expected maintenance (repair, replacement, etc.) tasks that may be required on the unit. The design engineers, construction supervisors, operators, and maintenance staff should then review the proposed design to determine if these tasks can be completed properly. Many problems and maintenance expenses can be avoided if minor changes are made at this stage of the design.

When the basic design (shell size, orientation, location, ductwork, etc.) has been specified, a complete laboratory flow model study should be made to determine the acceptability of the general design. Detailed engineering

TABLE 6-1. ERECTION SEQUENCE

Construction phase	Tolerances	Comment
Foundations	Elevation and bolt position	
Structural steel	± 1/16 in.	Level, plumb and diagonal dimensions. Shim supports to ± 1/16 in. elevation.
Subassembly of hoppers		
Set hoppers		Temporary support
Assemble side panels	1/8 in. weld	Flat work table for subsection welding horizontally on ground
Install side panels and base plates		
Base girders installation		
Rod bracing and guide wires		Alignment-check diagonals, centerline position
Roof girders	± 1/8 in. individual ± 1/8 in. diagonally	Girders parallel to each other, right angles to shell, top/bottom flanges level, and same elevation
Weld-bolted connections		Tack weld shell and bolts/nuts. Exterior bolts are to be seal welded
Seal welding		All shell seams
Inlet and Outlet nozzles and perforated plates		Assemble perforated plate, install on outlet nozzle, and seal-weld nozzle to shell. Assemble perforated plate, install on inlet nozzle, and seal-weld nozzle to shell

(continued)

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TABLE 6-1 (continued)

Construction phase	Tolerances	Comment
Lift hoppers into position		Bolt to structural steel, seal weld to side panels, and base girders
Assembly and installation of collecting plates	Plate warpage ± 1/16 in. overall length	Establish ESP centerline. Tack-weld captive spacer bar on roof girder lower flange. Lift plate cradle into field and secure. Move each plate into position using field trolley. Plate section subassembly anvils, stop plates, connecting links, etc. Align collection plates
Vertical flashing		Seal-weld between outside plate and shell in each field (leading and trailing edges)
Plate rapper bars, anvils, and stop (internal hammer design only)		Align rapper hammers and anvils for center strike.
Electrode support frame stabilizers		Straighten on ground before installation
Electrode support frame	Diagonals ± 1/16 in.	Assemble on ground. Install hammer assembly, anvils. Temporarily install electrode frame. Hang electrodes. Straighten electrodes to ±1/16 in.
Roof panels		Align and seal weld
Support insulators		Install insulator support gasket. Install insulator support. Install insulator. Install insulator cap. Mount support springs

(continued)

TABLE 6-1 (continued)

Construction phase	Tolerances	Comment
Alignment of electrode support frame		Lift electrode frame from temporary support. Align electrode support frame to center line of collection surfaces. Level support frame. Tack-weld insulator support to roof
Alignment of stabilizers and electrodes		Mount electrode frame stabilizers. Align upper and lower frames and align electrodes ±1/16 in. Hang electrode weights. Recheck electrode alignment
Insulator housing		Assemble and install insulator housing to roof. Seal-weld. Install rapper assembly. Install insulator heaters
Plate rapper		Install rappers and/or rapper drives. Position and rotate rapper hammer shaft for proper strike
Power supply and controls		Install T/R. Install bus duct, insulators, bus bars
Insulation		
Safety interlocks		
Conveyors, dump valves, air locks		
Miscellaneous equipment		

design and components can then be specified. The flow distribution is critical to achieving the design emission levels and must conform at least to IGCI specifications. Model studies only define the potential (optimum) flow pattern in the unit and not necessarily the operating flow patterns under dust conditions. Thus, several studies may be performed (with artificial deposits on turning vanes, distribution plates, or other surfaces) to determine the limits of a unit. The use of visual indicators (such as smoke) can indicate areas of turbulence or material deposition. Elimination of these areas can reduce maintenance problems in the full-scale unit and improve the overall on-line performance.

6.1.2 Specification of Materials

The vendor or manufacturer usually specifies the materials of construction as part of his bid submittal. In many cases, however, the purchaser, based on in-plant experience, may specify in detail the components, materials, or construction practices. Most specifications must be accepted as complying with national ratings or codes. Deviation from accepted normal practice must be clearly specified. Typical sources of ratings and codes are as follows:

Federal Specifications
Naval Facilities Engineering Command (NAVFAC)
U.S. Environmental Protection Agency (EPA)
American Iron and Steel Institute (AISI)
American Society for Testing and Materials (ASTM)
Industrial Gas Cleaning Institute (IGCI)
National Electrical Manufacturers Association (NEMA)
Occupational Safety and Health Administration (OSHA)
Sheet Metal and Air Conditioning Contractors National Association (SMACNA)
American Institute of Steel Construction (AISC)
International Electro Technical Commission (IEC)
Nuclear Regulatory Commission (NRC)

6.1.3 Selection of a Contractor

The selection of a general contractor to erect the ESP is very important. Because of the size of the job, bid requests may yield a large number of submittals from general contractors that have little or no experience in constructing ESP's. General contractors who are well qualified to complete major projects such as bridges, buildings, etc., may not be able to assemble an ESP to the required tolerances. Qualifications of potential bidders

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should be reviewed and previous jobs should be inspected for subsequent quality control and maintenance problems related to the original construction. It is generally more efficient to use the manufacturer or vendor as the general contractor because a single firm then has direct responsibility for the manufacture, delivery, storage, and erection of the unit; however, the use of others may not necessarily result in an inferior product.

6.1.4 Scheduling

Scheduling is necessary to maintain continuous and steady progress toward completion of the construction. The scheduling of major milestones is completed during the conception and design phases of the project. One area that is not always adequately addressed is the scheduling and receiving of material. The potential problems created by critical components arriving too early in the construction process can be greater than those resulting from delayed shipments. Many ESP components are sensitive to storage conditions, and long storage can severely damage them and cause failure during operation. The time must be projected for receipt of parts and storage options must be considered. An assessment of penalties may be considered for late delivery and also for early delivery that entails special handling and storage.

Close coordination between the plant and the vendor or manufacturer of the components is necessary to maintain projected construction schedules.

6.1.5 Inspection of Manufacturer's Facilities

The purchaser may reserve the option of inspecting the manufacturer's fabrication facilities prior to bid selection or after the contract award to ensure proper quality control during component fabrication. Most manufacturers will welcome a review of their quality control and production procedures. This may enable defects and/or fabrication errors to be discovered prior to shipment. Methods of crating, shipping, and special handling also may be addressed that will prevent damage in transit.

6.1.6 Quality Assurance/Quality Control

A quality assurance/quality control (QA/QC) program must be established for evaluation of each phase of the construction to certify that all component subassemblies and systems are manufactured and installed so as to meet or exceed design specifications. The program can be divided into two major

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elements: 1) inspection and acceptance of materials, and 2) quality control of construction and erection.

Inspection and acceptance of materials is a continuous process involving verification of the quality of the part or component at various stages of construction. During the design phase, acceptance is based on the established specifications; at this point, quality assurance and reliability of the product are determined, and changes are made as necessary.

The second phase involves the review and acceptance of the manufacturer's quality control program to prevent the production and shipment of defective components. The purchaser may require special tests or quality control checks. In the third phase, the purchaser or the general contractor must have a quality acceptance program for material received at the job site. This inspection is very important because it verifies receipt of the proper component and certifies that no in-transit damage has occurred. Acceptance of materials at this point releases the manufacturer from all claims except hidden damage or in-service failure (design flaw). Acceptance tests (nondestructive or destructive) may be performed on a sample of components, depending on past history of problems with this component.

Because components may be damaged during storage, a quality control check should be made of material as it is removed from storage, prior to its installation. No damaged material should be installed in the ESP.

The final phase of the QA/QC program involves quality control of construction practices and installation. Quality control checks should be completed at each major step in construction before further progress is allowed. Such checks prevent hidden defects or substandard construction that may require major renovation or demolition at a later date. The program may include alignment or clearance checks, welds, surface preparation, and materials of construction.

6.1.7 Onsite Material Storage

Quality control procedures for onsite storage of components requires special consideration. Plates, wire frames, electrodes, and insulators are critical components in the performance and reliability of the ESP. Improper onsite storage of these components can result in chronic maintenance problems after installation.

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The manufacturer fabricates plates and plate panel components (stiffeners, alignment rakes, etc.) to precision tolerances, and these components must be assembled in the final unit to a clearance of ±1/4 in. (discharge electrode to plate). If these items are stored flat, without adequate support, stress may cause alignment problems with the plates when they are placed in the heated gas stream (bows, bends, twist, etc.). Plates should be stored on edge and adequately supported. Wire frames also can be distorted as a result of improper storage, which prevents their alignment in the gas lane. Pipe frames (masts) are composed of hollow pipes, and in winter months, water may freeze in the inner surfaces and cause swelling and/or rupture of the pipes.

All components must be protected from weather to prevent corrosion if extended storage (greater than 1 yr) is required. Proper scheduling of the receipt of components will generally limit exposure to less than 60 days. Structural components (beams, plate, etc.) usually will be painted with a primer and will not require special treatment. Plates and wires are generally received unpainted, but surface corrosion is not a problem during short exposure.

Electrical and mechanical components (such as rappers, insulators, T/R sets, and control cabinets) should be stored in climate-controlled areas and protected from dust and physical damage.

6.1.8 Preoperational Inspection and Testing

Acceptance of the ESP after installation involves a series of predetermined steps including preoperational planning, acceptance testing, system transfer, and project completion.

Preoperational planning involves the transfer of technical information from the vendor and general contractor to plant operators and maintenance staff. This can include the development of operation and maintenance manuals, a work order system, recordkeeping requirements, and troubleshooting procedures. It can also include both internal and vendor training of the staff at a time when the components of the system are new, clean, and cold.

A schedule and procedure should be set up to verify the "as installed" versus the "as specified" system with regard to system components, materials of construction, etc. Checklists of step-by-step evaluation procedures should be prepared and the responsibilities of each person involved in the evaluation should be spelled out.

Several preoperational tests also can be conducted before the ESP system is transferred to operating personnel. The following are examples:

- Functional tests--Functional tests may be performed on an individual component to determine initial acceptance before a full gas-load evaluation. Functional tests include continuity checks of electrical controls, alarms, and motor circuits; verification of the rotation of motors, fans, and screw conveyors; and checks on the operation of major systems such as rappers and ash handling systems.
- Tests for air inleakage--The ESP shell should be checked for potential air inleakage at welds, access doors, and ash valves. Welds may be checked visually with vacuum boxes. All points of air inleakage should be repaired before further acceptance tests are made.
- Tests for electrical continuity and grounds--Physical inspection of the electrical distribution system should be made, and continuity of electrical connections should be verified. The electrical system also should be inspected to determine the possible presence of unintentional grounds. After the physical check, the electrical bus should be disconnected and each field should be meggered. A 1000 volt megger should be used and the resistance should be between 100 megs and infinity.
- Alignment tests--An internal inspection of the wire and plate alignment should be conducted to determine proper clearances. Any point of close clearance, warped plates, or poor fabrication should be corrected before air-load tests are conducted.
- Gas distribution--If any possibility of nonoptimum gas flow distribution exists, hot wire anemometer tests should be conducted. Fans should be dampered, and total gas volume and temperature for the test (Reynolds Number) should be defined. Velocity profiles should be produced at predetermined vertical locations and horizontal positions. The nonoptimum distribution may be downstream of the inlet distribution devices (between lanes) or at the outlet upstream of the last distribution devices. The average velocity (in feet per minute) and deviation should be calculated and compared against IGCI acceptance values as a minimum. Many users need and have much tighter requirements for gas flow distribution. Visual evaluation also may be made by using smoke systems and internal lighting. Any deviation from predicted performance should be corrected prior to startup.
- Air-load tests--The ESP should be closed, and key interlock procedures should be followed. Each T/R set should be energized, and after the control system function has been verified, the power should be increased to the current limit or flash-over (spark) point. The secondary voltage/current relationship should be plotted and the corona initiation and

spark points noted. Electrical clearances can be judged, based on comparison between fields. If any field deviates from predicted (design) values by ±10 percent, the alignment of the field should be reconfirmed.

6.1.9 System Transfer

An orderly transfer of the ESP's operation and maintenance should be made from the vendor and/or general contractor to the plant personnel. This transfer should occur over a short period of time, as operators and maintenance staff become trained and certified.

6.1.10 Project Completion

An ESP project is completed in phases: construction, mechanical and electrical check-out, startup, system operation, and acceptance tests. Acceptance tests generally are defined as verification of ESP efficiency or outlet mass loading under full load conditions. This test should be made in accordance with established EPA test protocol so that the manufacturer's guarantee acceptance test can be submitted to the appropriate regulatory agencies as initial proof of compliance. To determine reliability of the unit, a second acceptance test should be conducted after a period of sustained service (i.e., 6 months to 1 year). During this period, any hidden or previously undetermined defects may surface that limit the long-term removal efficiency of the unit. It is also good practice to establish a means for correcting from a given test condition to the contract test condition since volume flow rates frequently differ from specifications. Plots of guaranteed or outlet loading vs. volume flow rate are an acceptable method for this.

6.2 EXTERNAL INSPECTION

Because an external inspection of an ESP is generally conducted when the unit is in operation, it cannot provide direct information on the internal condition of the ESP. Internal conditions of the unit are reflected, however, in the electrical readings in each field. The external inspection involves checking major system components and determining their impact on electrical readings and indirectly on ESP collection efficiency. Components that are inspected include rappers and rapper controls, penthouse purge-air and heater systems, shell condition, ash-handling system, and flue gas characteristics. The following sections describe the procedures that may be used to evaluate the status of an ESP by inspecting these components. Because each vendor's equipment design is different, several of these items may not be directly applicable to all units.

6.2.1 Rappers and Rapper Control

The purpose of rappers is to remove dust that has been collected on the ESP plates, gas turning vanes, distribution plates, and discharge electrodes. If dust is not removed from the plates, the power input to the individual plate (electrical field) sections may be reduced. As dust depth increases, the voltage drop across the dust layer increases, which requires an increase in the T/R set secondary voltage to maintain a constant secondary current. Dust buildup on wires increases the effective wire diameter and corona initiation voltage. Heavy accumulation can completely quench the corona and/or cause premature sparkover as clearances are reduced. Buildup of dust on the turning vanes and perforated plates changes the gas distribution and velocity vector entering the ESP. Gas-flow models and efficiency calculations performed as part of the unit design assume that these surfaces are reasonably clean and the gas distribution is correct.

The level of dust collected on each surface is a function of dust loading, dust characteristics, gas characteristics, and unit design. Requirements for intensity and frequency of rapping may be unique for each unit and may change with process conditions and the age of the unit. It is important that each rapper function at design rapping intensity.

The four general types of rappers are pneumatic-impact, magnetic-impulse gravity-impact (MIGI), electric or pneumatic vibrators, and falling hammers. Each provides a different level and frequency of vibration to the surface. The application of each is based on the vendor's preference and the ESP application. Pneumatic rappers are generally used on plates and wires in the kraft pulp and cement industries, and MIGI rappers are generally used on plates and wires in industrial and utility boiler applications. Vibrators are also used on wires in the cement industry, and falling hammers are used for internal and external rapping in almost all applications.

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Rappers that are external to the ESP shell are easier to evaluate and maintain than are internal rappers. The first step in the inspection of external rappers is to verify that all rappers are functioning. This check requires the application of either electrical impulse or air pressure to each rapper to determine if it is operating. In the case of vibrators or pneumatic rappers, the inspector should note the sound of the rapper during its operation. Weak activity indicates needed repair. Manual triggers, solenoids, or electric relays may be installed to aid in the evaluation.

For proper operation of pneumatic rappers, the air must be dry and clean. When condensed water mixes with lubricating oils that are placed in the air lines for rapper lubrication, an emulsion forms that can combine with rust and cause seizure of the rapper piston. Air for the rappers should be equivalent to instrument air (dew point - 40°F). Air dryers, traps, and filters should be used as necessary to ensure proper operation of the rapper (see Figure 6-1). If air lines have been subjected to high levels of moisture and air quality is later improved, a secondary problem may occur; rust may flake off the line walls and foul the solenoid valves. It may be necessary to place filters prior to the solenoids to remove particles.

The fact that the rapper is functioning does not necessarily mean the rapping energy is being transferred to the collecting surface. Each rapper should be checked while it is operating to determine if it may have become disconnected from the rapper shaft and/or insulator.

Alignment of rapper shafts and rappers should be noted. Any movement in plate and wire frame alignment can cause misalignment of the rapper shaft and roof opening, with the possible result of breakage of insulators, rapper shafts, and/or anvils.

If the ESP does not have a penthouse and the roof is constructed of concrete, binding of the rapper shaft can cause structural failure. Dust buildup in the rapper top opening (nipple) can harden and cause the rapper to seize. Rapping under these conditions imparts rapping energy to the roof structure and can cause cracking. Each rapper should be moved laterally during the inspection to determine if the shaft is free in the opening.

Rubber boots around the rapper shafts should be inspected to determine if they are airtight. The rubber should be flexible and free of cracks (see

Figure 6-1. Rapper air line trap and filter.

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Figure 6-2). In many cases, the boot may be installed with the rapper shaft at one elevation, and over a period of time the shaft may shorten (as a result of wear, roof distortion, etc.) and cause the boot to fold. The folds hold water, which increases the rate of failure and inleakage. Exposure to high temperatures also increases the failure rate. It should be noted that Hypalon® and Viton® materials are now available to withstand high temperatures and chemical attack.

Manual activation of rappers does not ensure their proper automatic operation because the automatic controls may not be functioning. Periodically, the system should be checked completely to evaluate the control system. Because rapper operation may be less frequent in the outlet fields and the total number of rappers on the ESP may be excessive, the inspector cannot wait for each rapper to activate in the automatic mode. In this case, inspectors can use indirect methods, such as placing coins, washers, or other items on the rapper surface, to check rapper operation. If the rapper is activated, these items will fall off; when the inspector returns after a rapper cycle, it will be readily apparent which rappers did not activate. Depending on the complexity of the control circuits, rapper function in the automatic mode may also be confirmed by decreasing rapper frequency on the control board and pacing the rappers as they activate.

Evaluating falling-hammer rappers during ESP operation is difficult because the only visible moving component is the rapper shaft and drive. First, the inspector should note that the shaft is turning and estimate the approximate rate of rotation. If the number of hammers attached to the shaft is known, an equal number of rapping strikes should occur during each rotation. Because these strikes cannot be observed externally, indirect methods must be used. One effective method is to place a stethoscope against the ESP shell in the area of the rapper shaft. Each strike can be heard, and if the numeric location of the rapping sequence is known, the approximate location of poor or missing anvils can be identified. Common failures of these rappers involve offcenter impact on the anvils, slippage of hammers on the shaft, and separation of the anvil shaft from the plate. An internal inspection is necessary for a complete evaluation of these rappers. Seals around

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Figure 6-2. Rapper boots.

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the rapper shaft should be checked to determine if air inleakage is occurring.

6.2.2 Penthouse Purge Fans and Air Heaters

Depending on the vendor, ESP purge fans may be located in a penthouse or in an insulator enclosure (see Figure 6-3). These fans are designed to provide a constant flow of clean, dry air across the insulator surface where the wire frame support shafts (rods) penetrate the shell to prevent dust contained in the flue gases from being deposited on the insulators and causing electrical tracking. Generally, only a small amount of purge air is required, i.e., just enough to pressurize the penthouse or enclosure above the pressure in the gas treatment zone.

The inspector should verify that the purge fans are functioning. The amount of air being provided is not usually determined, but the effectiveness can be evaluated during an internal inspection of the penthouse or insulator enclosure. Dust accumulation may indicate poor purge rates. Filters should be used on fan intakes where foreign matter is present to prevent dust from being blown into the penthouse, and these filters should be changed periodically to prevent reduction in purge volume. Ammeters may serve as an indirect indicator of fan volume and when it is time to change the filters.

Purge-air heaters may or may not be required on individual units, depending on operating temperatures and design. The purpose of the heaters is to prevent local quenching of hot flue gas as cold outside purge air is introduced. This quenching can result in condensation of water or other condensible material in the flue gases in the insulator or under the ESP roof. The extent of the condensation is site-specific and depends on the moisture and temperature of the flue gas, the moisture and temperature of the outside air, the temperature in the penthouse (as a result of heat loss through the roof), and the rate of penthouse purge. If condensation tends to form in the insulator (as indicated by hardened dust deposits, corrosion in the inner roof, or condensation in the penthouse), heaters should be used.

Heating purge air is expensive because 5.5 kW is required for each insulator. Contact heaters (which only require 0.4 kW/insulator) mounted on the insulator are now in common use on many dry dust ESP's. The most critical period for penthouse heating is during startup, when metal surfaces are

Figure 6-3. Penthouse heater and fan.

cold and any additional heat loss may result in condensation. The inspector should verify heater function by using permanent ammeters or portable hand-held amp probes for each purge-air unit.

6.2.3 Insulator Heaters

Many vendors provide direct insulator heaters to maintain wire frame support insulators above air dew points. These heaters cannot be inspected during ESP operation; their operation can only be verified by measuring the amount of current to the heater. Typically, these are resistance-type heaters enclosed in a ceramic body. The inspector should determine the status of the heaters by using permanently installed ammeters or portable amp probes. The units may or may not be thermostatically controlled. The inspector should define current levels by using a normal baseline; any deviation indicates low heat rates, short circuits, or open circuits in the system.

As with purge-air heaters, the proper functioning of the insulator heaters may not be critical for an individual unit, but it is critical during startup to protect the insulators from condensation and electrical tracking.

6.2.4 ESP Shell and Doors

For proper ESP operation, the shell must be as airtight as possible. Any inleakage of ambient air into the enclosure produces local changes in the gas stream characteristics (temperature, moisture, oxygen, etc.). Depending on the location of the inleakage, the electrical field may flash-over (spark) at a lower voltage and current or cause dust buildup on the plates and wires. If the inleakage is in the hopper area, collected dust may become reentrained in the gas stream and lower the unit's efficiency. Severe gas inleakage (in ducts, doors, roof, etc.) can generally suppress the flue gas temperature, cause corrosion, and increase the gas volume to be treated (i.e., reduce treatment time, increase the superficial velocity, and decrease the SCA). The inspector should audibly check doors, hatches, flanges, rapper shaft boots, etc., to determine if there is an inrush of air. Rapper boot corrosion is shown in Figure 6-4. On cooler surfaces, air inleakage may also be determined by touch. Smoke generators also may be used as indicators of poor sealing. Air inleakage is a constant problem that must be judged by a number of indirect indicators, including inspection of the following: door gaskets,

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Figure 6-4. Example of rapper boot corrosion.

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shaft seal and boots, temperature drop from inlet to outlet of the collector, increase in flue gas oxygen from inlet to outlet of the collector, and patterns in the electrical power readings. Each point of inleakage should be noted, and possible corrosion should be checked during an internal inspection.

In many systems, shell corrosion occurs from the inside of the unit (moist and corrosive gas stream) and does not become visible from the outside until complete failure has occurred. Dust deposits may hide this type of corrosion during internal inspection, or it may occur in an inaccessible area. The inspector should be careful to note any areas that show distortion, abnormal flexing, or any changes in appearance that could indicate thin metal. Areas of most concern are the roof, the areas around door or hatches, isolation plates (guillotines), and expansion joints.

6.2.5 Electrical Conduit Ducts

Wire or metal pipe conductors transfer the electrical power (DC) from the T-R set to the discharge wire frame. This power has a high negative potential (20 to 55 kV) and cannot be insulated by conventional methods. The conductor is isolated from personnel by an enclosure (duct) and an air gap between the conductor and duct to prevent electrical arcing. The conductor is supported by post insulators located in the duct and on the T-R set.

Changes in the air in the duct due to moisture or condensation on the insulators can cause arcing of the high voltage to ground. These arcs are audible when the arc strikes the duct wall, and electrical meters fluctuate wildly in the field. If they are severe, continuous, and stronger than the control circuits are designed to handle (higher current than sparking), these arcs can cause overheating of the transformer and linear reactor.

The inspector should take note of any indication of arcing in the duct (and on meters) and determine if the arc may have been caused by air inleakage into the duct, water penetration, or some external influence. An example of conduit corrosion is shown in Figure 6-5. Heavy, uncontrolled arcing may necessitate isolating the field to prevent permanent damage to the T-R and control circuits.

If external causes cannot be determined, an internal inspection may be necessary during an outage. Arcing can be caused by dust buildup on post

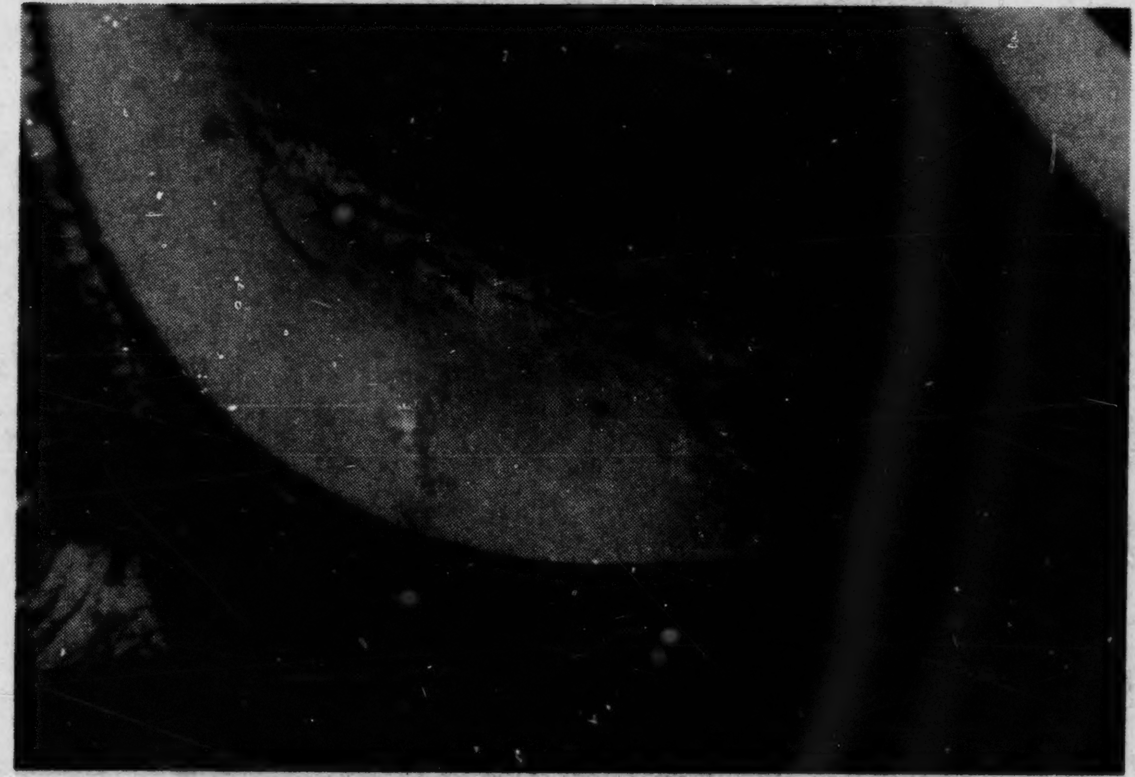

Figure 6-5. Electrical conduit corrosion.

insulators, condensation, or reduced clearances resulting from movement of the conductor.

Depending on vendor preference and equipment location, the conduit may (or may not) be vented externally or with the purge-air system. If the system is purged, vent openings should be checked to ensure proper air flow.

6.2.6 Control Cabinets

The area in which the T-R set control cabinets are located should be clean and supplied with cool air. Transformers and resistors in the cabinets generate heat, which must be removed through finned surfaces. Generally, a water chiller or an air conditioning system is provided in the area to remove heat and maintain a moderate cabinet temperature (less than 90°F). Failure to remove heat can result in failure of solid-state printed-circuit control boards.

Dust in cabinets also can cause electrical short circuits and increase heat retention. If independent cabinet ventilation is used, each cabinet should be equipped with air filters; if independent cabinet ventilation is not used, the room air should be filtered.

The inspector should visually check the condition of the filters to determine if dust has accumulated on electrical components. Under no circumstances should the inspector penetrate the cabinet while it is energized because it presents a potential shock hazard.

The inspector should note any evidence of corrosion in electrical contacts, relays, and circuit boards. Deterioration may be expected in areas where hydrogen sulfide or sulfur dioxide is present. Severe corrosion can cause loss of the electrical conductor or components in the printed circuit boards. If the problem is chronic, room filters (activated carbon) may be required.

6.2.7 Key Interlock System

The inspector should visually inspect the key interlock system to determine that all-weather enclosures are in place and that interlocks have not been removed. The operation of the individual locks should be verified during entry procedures associated with an internal inspection of the unit.

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Most interlock hardware is manufactured from brass alloys, and a certain amount of tarnish and surface corrosion is expected in an industrial environment. Internal corrosion of locks and tumblers can produce operating problems and replacement may be necessary. A dry lubricant (graphite) should be used on the interlock in lieu of oils or greases because the latter will hold the dirt.

6.2.8 Ash-Handling System

The ash-handling system is the final discharge point for collected dust. Depending on application, system components can consist of hoppers, drag bottoms, and wet bottoms. Regardless of the system used, however, the collected dust must be discharged at an average rate equal to that at which it is collected. Short-term deviations are acceptable as long as the capacity of the hopper to store the dust is not exceeded.

Generally, an inspection of the ash-handling system entails verifying that no hoppers are plugged and that the level of collected dust has not exceeded the high-level alarm point.

In drag-bottom ash-handling systems, an inspection is conducted to verify that the drag scraper is in motion and that material is being properly discharged to the screw or mixer. Because the drive motor can continue to operate after the chain has broken or the drive shaft has sheared, an external evaluation is not adequate. Current drawn by the drive motors can be used to indicate heavy buildup or free motion, but this may not provide full protection.

Positive-motion indicators have been developed that are connected to electrical counters outside the shell and sound an alarm if contact is not completed within a specified period of time (i.e., motion each time a scraper blade strikes the arm). Instruments of this type prevent major drag scraper damage and the excessive downtime that can occur when chains break and drags become misaligned.

Heavier dust discharge rates are required in the inlet field because of the heavier collection there. Chamber-to-chamber variation also may result from gas-flow imbalances and dust stratification. Adjustments of each hopper evacuation rate and frequency must be based on site-specific factors. Hoppers with chronic pluggage problems may be influenced by rapid cooling from prevailing winds or other thermal sources, and windscreens may be required to reduce these thermal effects. The inspector also should verify the operation of hopper heaters (if used), vibrators, and air stones.

Inspectors may use the vacuum chart on the suction withdrawal side of the system to evaluate hopper evacuation times. A premature vacuum break may be an indication of rat-holing or hopper bridging. The time required to empty specific hoppers (inlet/outlet fields) should be consistent under normal operation (full load/half load, etc.); any deviation may indicate incomplete removal or pluggage problems.

6.2.9 Gas Stream Conditions

Variations in the flue gas stream can cause ESP performance to deviate seriously from design operation. Variables that must be considered are gas temperature, moisture content, and volume. Some of these items cannot be determined during a routine inspection, and a Method 5 stack test may be necessary; however, others may be measured directly or inferred from surrogate factors.

Temperature--

The inspector should record the flue gas temperature at the inlet and outlet of the ESP and compare these values against normal operating ranges. Deviations can cause reduced power (resistivity effects), premature flashover (sparking), corrosion, or changes in the flue gas volume treated. Both positive and negative deviations are important.

The temperature across an ESP is rarely uniform; a variation of 20° to 100°F is not uncommon. Multiple thermocouple locations are desirable to determine changes from normal operation.

If gas stream temperature is controlled by evaporative coolers that humidify the gas stream (typically used in the cement industry), the temperature can be related to flue gas moisture. In these applications, the resistivity of the dust layer is controlled by the water vapor. Changes in temperature may be a significant indirect indicator of the flue gas moisture. Temperature measurements should be correlated with inspection and monitoring of the evaporative cooler.

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Flue Gas Oxygen--

Flue gas oxygen by itself is not critical in ESP performance, but changes in flue gas oxygen indicate a change in the process operation that the ESP is serving or possible inleakage to the flue gas stream.

Most combustion process flue gas streams contain a residual amount of excess oxygen that can be limited to increase combustion efficiency. An increase in excess air results in an increase in flue gas volume at the same boiler load. If the boiler was designed for 10.5 percent (2.0% O_2) excess air and the level of excess air were to increase to 50 percent (7.0% O_2), the flue gas volume would increase by 36 percent. The increased gas flow would reduce the effective SCA of the unit and consequently the collection efficiency. Duct corrosion and flange leaks also can increase the flue gas volume over several months or years. In addition, many operators may allow boiler excess air to increase to undesirable levels.

Oxygen content in the flue gas should be measured periodically, before and after the ESP, with portable instruments (if permanent instruments are not installed). Typically, boiler operating instruments are installed at the boiler outlet or the economizer outlet, and they do not necessarily reflect ESP conditions.

Flue Gas Volume--

The flue gas volume being handled by the ESP directly affects the performance of the unit. Typically, absolute values of gas volume are determined by stack test, and they may or may not be applicable on a day-to-day basis because of variations in excess air, inleakage, process load, or temperature.

Flue gas volume may be estimated by adjusting known volumes (process generating rates) for changes in temperature or excess air (oxygen content). These methods (generally defined as F-factor estimates) can produce gas volume estimates within ±10 percent of the true gas flow.

Another method of estimating gas volume is by noting the current drawn by gas moving devices or fans. If current is used, the absolute value must be normalized to the same fan rpm and flue gas temperature. This method also may be used where parallel chambers are vented through two identical fan units. For optimum performance, each chamber should treat the same gas volume.

6.2.10 Process Influences

When making an external inspection of the ESP, the inspector must consider the constraints and conditions placed on the unit by the process to which it is applied. Flue gas volume, temperature, moisture dust loading, particle size distribution, particle chemistry, resistivity, and gas composition are all determined by the process variables. During inspections, the tendency is to ignore the influence of the process variables on ESP performance. The inspector must document all process operating conditions that have an impact on the flue gas or particulate conditions. On the surface, these process conditions may not appear to influence ESP operation, but they can have an indirect impact.

Tables 6-2, 6-3, and 6-4 list several important process parameters for utility and industrial boilers, cement kilns, and kraft recovery boiler applications, respectively. The items are not all-inclusive; a review of each source is required to define site-specific parameters.

6.2.11 Opacity

The inspector should observe the condition of the ESP stack and make opacity readings in accordance with EPA Method 9 procedures. These readings should be made at 15-second intervals and averaged over a 6-minute period. The total opacity evaluation time should be at least 30 minutes and preferably extend over one ESP rapper cycle. The 6-minute averages should be plotted to identify any cyclic patterns that might indicate rapper failure.

If the ESP is equipped with an opacity monitor, the inspector should record the current 6-minute average opacity and note any patterns that are evident in the previous 2 to 4 hours of strip chart recordings. With the monitor placed in the real-time output mode (integration time set to zero), the frequency and magnitude of rapper reentrainment spikes should be evaluated. Rapper reentrainment spikes are generally caused by outlet field rappers. If the spike pattern indicates that reentrainment is resulting from inlet or midfields, overrapping may be occurring when gas velocity is too high in the treatment zones.

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TABLE 6-2. KEY PROCESS PARAMETERS FOR UTILITY AND INDUSTRIAL BOILERS

Flue gas temperature (economizer outlet), °F
Flue gas oxygen (economizer outlet), %
Fuel feed rate, tons/h
Fuel moisture (wood, bark, etc.), %
Fuel sulfur (coal), %
Fuel ash (coal, wood, etc.), %
Fly ash carbon (wood/coal), %
Pyrite reject rate (coal), tons/h
Ash composition (coal)

TABLE 6-3. KEY PROCESS PARAMETERS FOR CEMENT KILNS

Process (dry, wet, preheater, precalciner)
Raw material feed rate, tons/h
Composition ($CaCO_3$, FeO, CaO, Al_2O, Na_2O, K_2O, SO_4^-, Al^-, etc.)
Moisture, %
Clinker production rate, tons/h
Fuel rate, tons/h
Fuel type
Burning zone temperature, °F
Back-end temperature, °F
Flue gas oxygen, %
Insuflation rate, tons/h
Insuflation composition (Na_2O, K_2O, etc.)
Kiln speed (revolutions per hour)
Type of cement produced (Types I through V)

TABLE 6-4. KEY PROCESS PARAMETERS FOR KRAFT RECOVERY BOILERS

Boiler type
Evaporator type
Black liquor rate (BL), gal/min
Black liquor solids (BLS), %
Black liquor (chlorides), %
Soot blowing rate, 10^3 lb/h
BLS into evaporator, %
BLS out of evaporator, %
Flue gas oxygen, %
Flue gas temperature, °F
Char bed height, ft
Char bed temperature, °F
Primary air temperature, °F
Primary air flow, 10^3 lb/h
Brine rate, gal/min
Brine solids, %
Oil firing rate, gal/min
Salt cake pH (ESP)

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If monitors are installed on multiple chambers, average and instantaneous opacity values for each chamber should be compared. Deviations that cannot be explained by gas-flow deviations, particle segregation, and stratification may indicate rapping problems, clearance deviations, or distribution plate pluggage. Deviations should also be correlated with the ESP power input and pattern in each chamber.

6.2.12 Electrical Power Readings

The electrical power readings in each field provide an indication of ESP conditions. Whereas the primary current and voltage reading provide a significant amount of information on the performance of the unit (because they are on the line side of the T-R), they cannot directly measure the current and voltage characteristics of the electrical field between the plates and wires. The secondary current and voltage (as measured in most modern ESP control circuits), however, provide detailed information on the electrical field force and current flow in each section of the ESP.

For example, no voltage on the secondary side may be due to an open primary circuit. The circuit breaker may be open or tripped or a reactor secondary may be open. High voltage on the primary side and no voltage on the secondary side may be due to a faulty, open, or disconnected T-R set; an open bus; or a faulty rectifier. Low voltage on the secondary side coupled with low voltage on the primary side could be the result of leaks in the high-voltage insulation, buildup of dust in the discharge system, excessive dust on the electrodes, or swinging electrodes.

No secondary current and no secondary voltage indicate an open primary circuit. Irregular secondary current coupled with low secondary voltage indicates a high-resistance short in the circuit. This condition may be caused by excessive dust or arcing.

The inspector should record both primary and secondary meter readings during each inspection. In any reading, deviation from normal values should be noted, and the data should be correlated with other data obtained during the inspection (i.e., rapper function, flow distribution, process conditions, internal inspection data, etc.). The secondary current levels in each field/bus section should be plotted for each field from inlet to outlet. Generally,

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current levels should increase as dust is removed from the gas stream. The rate of increase and final values are site-specific and vary with gas stream conditions. A baseline or reference value should be established during acceptance tests or compliance tests.

If the internal conditions and gas conditions (flow rate, temperature, dust loading, etc.) are similar in parallel chambers, the electrical readings should be comparable. Deviations should be used to target investigation during the internal inspection.

Power levels vary with process conditions that modify ash and gas stream characteristics. Deviations that cannot be related to physical ranges in the unit can be correlated with process variables, such as fuel changes, excess air, boiler load, or raw material chemistry.

In recording and evaluating ESP meter readings, the inspector should recognize that the first indicator of ESP performance levels is the trend observed in the voltage and current levels over time. Specifically, the ESP secondary current levels should show a gradual rise from the inlet to the outlet fields (see Figure 6-6). No numerical scale is given for secondary current milliamps in Figure 6-6 because the secondary current in milliamps is a function of the number of feet of wire per field, and that information was not available for this example. Depending on field size, the secondary current level seldom exceeds 250 mA in the inlet fields. Typical designs call for a current level of 0.02 mA per linear foot of wire length in the inlet fields. Sparking in the inlet fields is usually indicated by deflection of the meters. When the meters indicate progression toward the outlet field, the secondary current levels should increase and sparking should decrease, with almost no sparking occurring at the outlet. The T-R current levels of most ESP outlet fields should be at least 85 percent of the T-R set current rating (e.g., if the secondary current rating is 1000 mA on the outlet T-R, a reading of at least 850 mA can normally be expected in the design) and in the range of 0.06 to 0.10 mA per linear foot of discharge wire.

Another trend that is evident in some ESP's is a gradual decrease in the secondary voltage from inlet to outlet. In larger ESP's (with five fields or more), voltages often decrease in the inlet field (due to sparking), increase in the middle fields, and then decrease slightly in the outlet fields.

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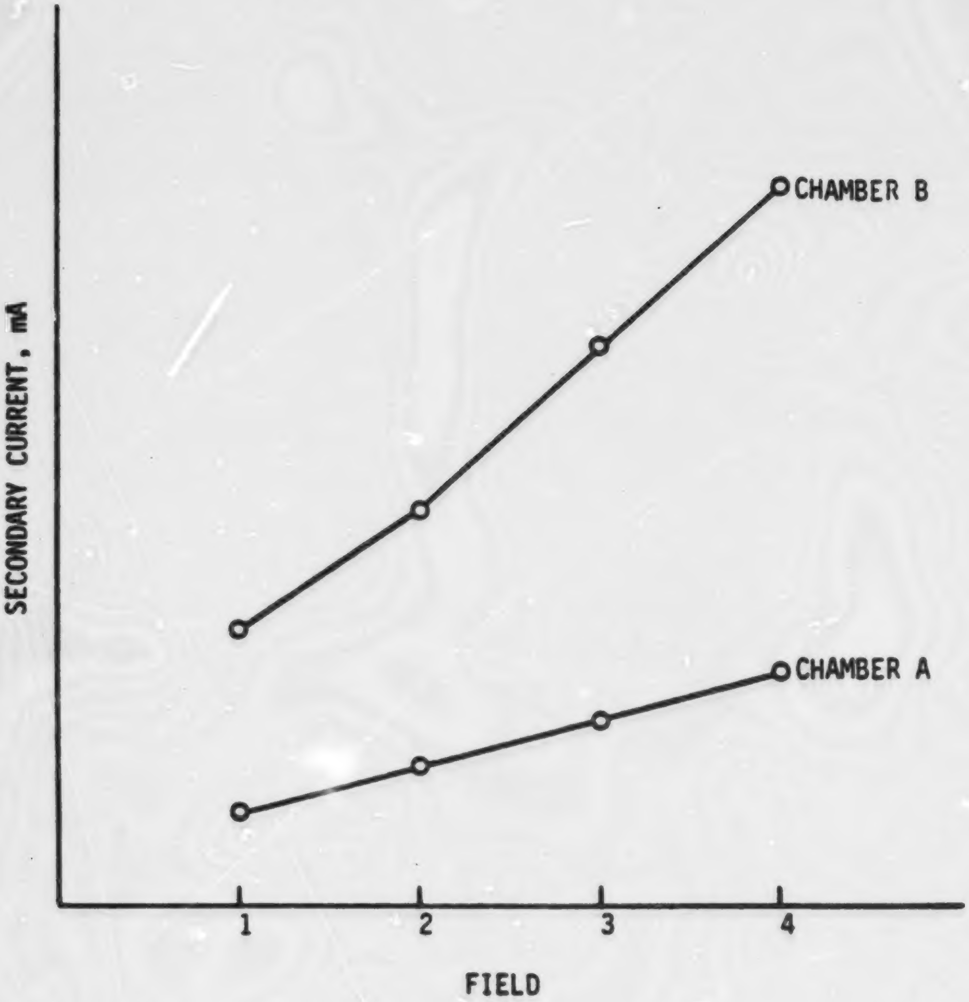

Figure 6-6. Example of secondary current pattern for two chambers with Chamber A having maintenance problems that limit power input.

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The gas entering the inlet field of an ESP contains the greatest concentration of particles. Because the greatest quantity of particle charging occurs in this field, many ions are captured during charging. The rate of charge transfer from the discharge to the collection electrodes is thus reduced because the mass of the particles migrating toward the plates is considerably larger than that of the ions (ion mobility). In addition, more force is required to move the electrons from the corona discharge to the collecting plates because the charged particles in the interelectrode space act as a large negative cloud that repels the ions. The greatest amount of sparking occurs in the first field, as this large cloud of charged particles increases the electric field adjacent to the plate, leading to gas breakdown (spark formation).

As the gas moves through the ESP and the particles migrate to the plate, there are fewer particles to capture and inhibit the flow of electrons; therefore, less force (voltage) is required to obtain a high current flow. Usually the increase in current is much greater than the decrease in voltage, and the net effect is an increase in power input from ESP inlet to outlet.

The relationship or ratio between voltage and current levels for each T-R is not constant throughout the ESP (from inlet to outlet). Changes in the voltage-current relationship are due to capacitance and resistance characteristics of the particulates and to inefficiencies in the circuitry of the T-R set at various operating levels. For the same reasons, the relationship between the primary and secondary voltage and current levels also will not be constant from inlet to outlet. Thus, general relationships between primary and secondary meter readings are difficult to establish and will change with dust characteristics. Over very narrow operating ranges within a T-R, however, the relationship between primary and secondary voltage and current levels may be considered linear. This linear relationship is useful in the evaluation of ESP performance if a secondary meter is out of service and the corresponding primary meter on the other side of the transformer is operating.

Whereas the trends in the voltage and current levels are important in evaluating ESP performance, corona power input is one of the most useful indicators of ESP performance. Secondary meters are preferred for determining corona power because they are more indicative of actual power input to

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the ESP. Primary meters may be used for this calculation, however, if they are the only meters available, provided an appropriate efficiency factor is applied. Corona power input is simply the product of the secondary voltage multiplied by the secondary current to yield watts of power to the ESP field from the T-R. This value should be calculated for each field of the ESP. When both primary and secondary meters are available, the primary voltage and current levels should be multiplied to yield the primary power input to the T-R in watts. The value of the primary meter product must be higher than that obtained from the secondary meter product. If the secondary power product (corona power) is the higher of the two, the values on the meters are incorrect. Isolating the malfunctioning meter, however, may be very difficult.

Electrical losses occur in the T-R during increases in voltage and rectification to an unfiltered DC wave form. Losses in the T-R control circuitry also reduce the efficiency of the transfer from primary input power to secondary corona power. The apparent efficiency factor for the T-R can be calculated by use of the ratio of secondary power to primary power:

$$\text{Apparent T-R efficiency} = \frac{\text{secondary power}}{\text{primary power}} \qquad \text{(Eq. 1)}$$

As mentioned in Section 3.1.1, this efficiency value is apparent because it encompasses two different methods of measuring current and voltage (i.e., RMS on the primary side vs. average on the secondary side). The apparent T-R efficiency value usually ranges from 0.55 to 0.85, although the theoretical maximum conversion efficiency of a silicon T-R is only 0.77. Apparent values as high as 0.90 are occasionally noted. Again, with the exception of a malfunctioning meter, the actual values obtained from the meters are not as important as the patterns that are created by these values. In general, the value of the T-R efficiency increases as the T-R approaches its rated output current level. Thus, T-R efficiencies tend to be lower in the inlet fields (0.55 to 0.60) and higher in the outlet fields (0.80 to 0.85) because of limitations imposed on the electrical operating characteristics by particulate loading and space-charging. A value of 0.70 to 0.75 is usually appropriate for use as an average for all fields in the ESP.

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Another item that should be checked in multichambered ESP's with T-R's for each chamber is the balance of power across the ESP. The secondary current level and power input for each field should be approximately equal across the ESP. Although some relatively small differences (2 to 5%) may occur because of rapper sequencing, slight gas-flow imbalances, or differences in internal alignment, these differences should not be large in most ESP designs, as chambers with equal gas flow and equal power levels give the best ESP performance. Temperature variations across the face of the ESP, however, may upset the balance of power.

When the power levels have been calculated and the patterns have been checked (as previously discussed), the corona power from each T-R should be added together to determine total corona power to the ESP (in watts). When multichambered ESP's having T-R's serving each individual chamber are installed, the corona power levels should be totalled for each chamber (to indicate balanced power) and an overall total corona power level should be calculated for all chambers.

If available, baseline test values should be compared with the actual secondary current and corona power levels. If the gas volume through the ESP is identical to the test value and the meter readings are also very similar, ESP performance is usually much the same as that observed during the stack test. Comparing design power levels with performance levels is usually impossible, as power levels are rarely included in design information.

A key indicator of ESP performance is the specific corona power, which is a useful value in determining whether ESP performance has changed significantly over time.

Specific corona power is calculated by the following equation:

$$\text{Specific corona power} = \frac{\text{total corona power (watts)}}{\text{total gas volume (1000 acfm)}} \qquad \text{(Eq. 2)}$$

This value may be calculated for the entire ESP or for individual chambers. In general, the higher the value of the specific corona power, the higher the ESP removal efficiency is. Thus, an evaluation of the specific corona power indicates whether the ESP performance would be expected to increase or decrease.

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Power density (watts/ft^2 plate area) is another useful indicator of ESP performance. The value for power density may be calculated by the following equation:

$$\text{Power density} = \frac{\text{corona power input}}{\text{ft}^2 \text{ plate area}} \qquad \text{(Eq. 3)}$$

This calculation may be performed for each field by substituting into the equation the T-R corona power and the plate area associated with that T-R. The increasing power density that should be evident from inlet to outlet may range from 0.25 W/ft^2 at the inlet to as high as 5 W/ft^2 in the outlet field. This calculation is useful for ESP's in which the fields are not of equal size. Although the increase of secondary current and corona power does not progress smoothly, this calculation will help "normalize" the values. A corresponding calculation may be performed on the secondary current (current density, mA/ft^2) to normalize the data.

By substituting total corona power and total plate area into the equation, one can usually determine the overall power density. Typical values are 1 to 2 W/ft^2, and these usually indicate good performance. As with specific corona power, however, performance may be poor even though the power density is high. Again, the inspector must rely on his/her background and experience to make judgments regarding performance.

The inspector can use a baseline test to calculate ESP efficiency. Total corona power, gas volume, and efficiency or penetration (1 - efficiency) are calculated in the baseline test, and these values can be used, along with a modified version of the Deutsch-Anderson equation, to calculate a constant for use in subsequent calculations:[1]

$$P_t = e^{-0.06\ K(Pc/Q)} \qquad \text{(Eq. 4)}$$

where

P_t = penetration

K = constant

Pc = corona power, watts

Q = gas flow, 1000 acfm

This equation relates corona power input and gas flow to ESP performance, whereas the original form of the Deutsch-Anderson equation assumed maximum and nonvarying field density and related particle migration rate to the SCA of the ESP. The particle migration rate, however, is a function of corona power input; thus, corona power changes the particle migration rate and the ESP efficiency. This equation is useful for predicting changes in efficiency if wide variations in the specific corona power have not occurred or the power distribution within the ESP is not seriously altered. Figure 6-7 illustrates the efficiency of a coal-fired utility boiler ESP as a function of corona power.

The value of "K" will typically be in the range of 0.1 to 0.25 for most kraft recovery boilers and 0.35 to 0.55 for utility boilers. When the value of the constant has been calculated, it may be applied in subsequent calculations in which inspection data are used. Because the equation usually will overpredict performance within narrow operating ranges, the predicted efficiency is based on the assumption that all the power is used to collect particulate. If the specific corona power decreases substantially however, the equation may greatly underpredict performance because the equation becomes very sensitive to variations in the specific corona power. In fact, the value of the constant begins to change with substantial increases or decreases of specific corona power, and the predicted performance can be incorrect by as much as half an order of magnitude when applied over a very wide range of specific corona power. The value of the constant and the behavior of the ESP will also change if T-R's become inoperative (particularly those in the inlet fields). Nevertheless, the equation will provide a gross indication of a performance shift.

The underlying limitation of the equation is the assumption that power input and changes in power input are the only factors that affect ESP performance once the SCA and gas volume are fixed and that the value of the constant and the effective migration velocity are related by a linear relationship. Actually, the relationship in the value of the exponent is probably a power function similar to that presented in the Matts-Öhnfeldt equation, which makes the equation less sensitive to variations in power input. Care

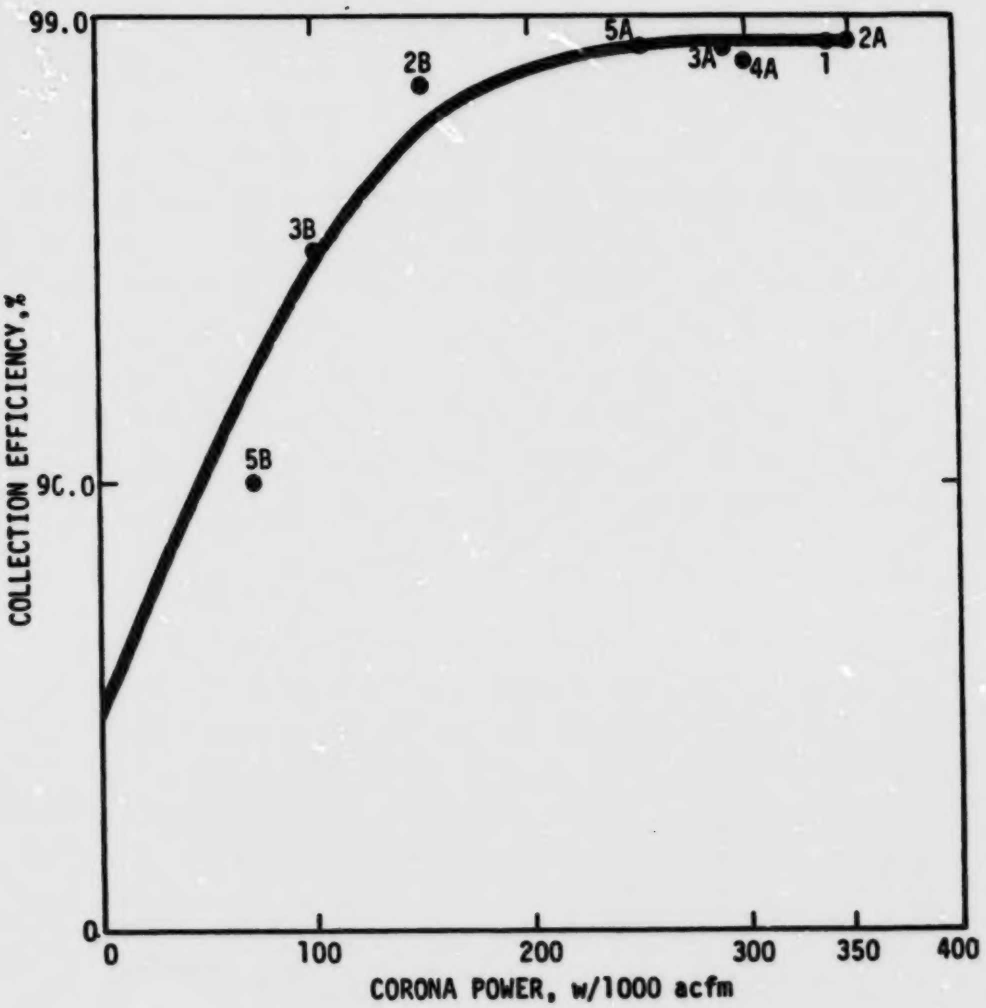

Figure 6-7. Corona power versus collection efficiency for a coal-fired utility boiler.[3]

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must be exercised when an equation is used at conditions different from baseline values.

In summary, the external evaluation of ESP data includes plotting the secondary current to discern an increase from inlet to outlet; calculating corona power from primary or secondary meters; evaluating the balance between the readings in parallel fields; calculating total corona power, power density, and specific corona power; and comparing these values with baseline readings. If conditions are nearly identical, performance is likely to be similar. Even if conditions are not identical, the inspector can draw some conclusions regarding performance based on major deviations from the established baseline conditions. For small changes of specific corona power, an indication of the magnitude of any performance shift may be estimated by use of a modified form of the Deutsch-Anderson equation. This equation should not be used when gross changes in ESP operation have occurred unless the values are modified appropriately.

6.3 INTERNAL INSPECTION

Proper O&M must include the internal inspection of an ESP, including ductwork, the electrical system, and the ash handling system. Periodic internal inspections are usually part of routine preventive maintenance activities or part of troubleshooting (diagnostic) evaluations. The data obtained must be combined with on-line evaluations to assess the ESP's condition adequately and to define needed maintenance or changes in the operation of the unit.

Before an internal inspection is begun, the reason for and scope of the inspection should be defined. The detail and scope of any internal inspection may be limited by time availability, resources, personnel, and accessibility. Annual internal inspections are generally necessary to determine hidden problems, to conduct scheduled repairs, or to make design changes. These more lengthy and involved inspections require exceptional planning and coordination.

Any diagnostic testing that is to be done during an outage, should take place before the dust layers on electrodes and plates (air load tests, dust depth, dust analysis, etc.) are disturbed.

The normal inspection procedure involves several access areas in the ESP and the entry of many personnel during outages (prerap periods, post-rap periods, post-wash-out, preclose-up, etc.). Each inspection is performed under different conditions to acquire specific information.

The following sections describe the areas that should be inspected, the method of inspection, possible malfunctions, and the effect these deficiencies may have on ESP operation.

6.3.1 Inlet Plenum

The inspector should check the gas-turning vanes in the ductwork entering the ESP. Vanes should be relatively free of dust accumulation and not eroded or corroded. Gas-turning devices are designed through scale model studies, and changes in gas-flow sectors or volume (chamber bias) can result in serious maldistribution of gas velocity over the ESP inlet. Deviation of the average velocity from the IGCI standard[2] reduces the potential collection efficiency of the collector especially for marginally-sized units. Figure 6-8 shows gas velocity distribution patterns resulting from improper gas distribution at the inlet plenum of the unit. As shown, the entry of high gas velocities in several areas of the collector results in lower gas treatment time, turbulence, high superficial velocity, and increased rapping reentrainment.

Areas of dust accumulation in the inlet nozzles should be noted, and changes in gas distribution, vibrators, or rapper frequency should be made to eliminate these deposits. Increases in the depth of dust deposits can change the inlet gas velocity profiles. Extension of the perforated plate to the floor of the dust can impound the dust and prohibit it from flowing into the inlet field hopper. Slotted openings at the bottom of the distribution plate can allow dust movement without changing the velocity across the plate. If the dust deposits continue to be a problem and normal remedies do not work, the rate of accumulation can be estimated and the dust can be removed during scheduled outages before it interferes with ESP performance.

The inlet plenum should be inspected for corrosion in areas where air inleakage has occurred. These areas may be associated with hard dust deposits, poor exterior insulation, or surfaces with maximum heat loss (prevailing wind direction). Each penetration point should be repaired and sealed.

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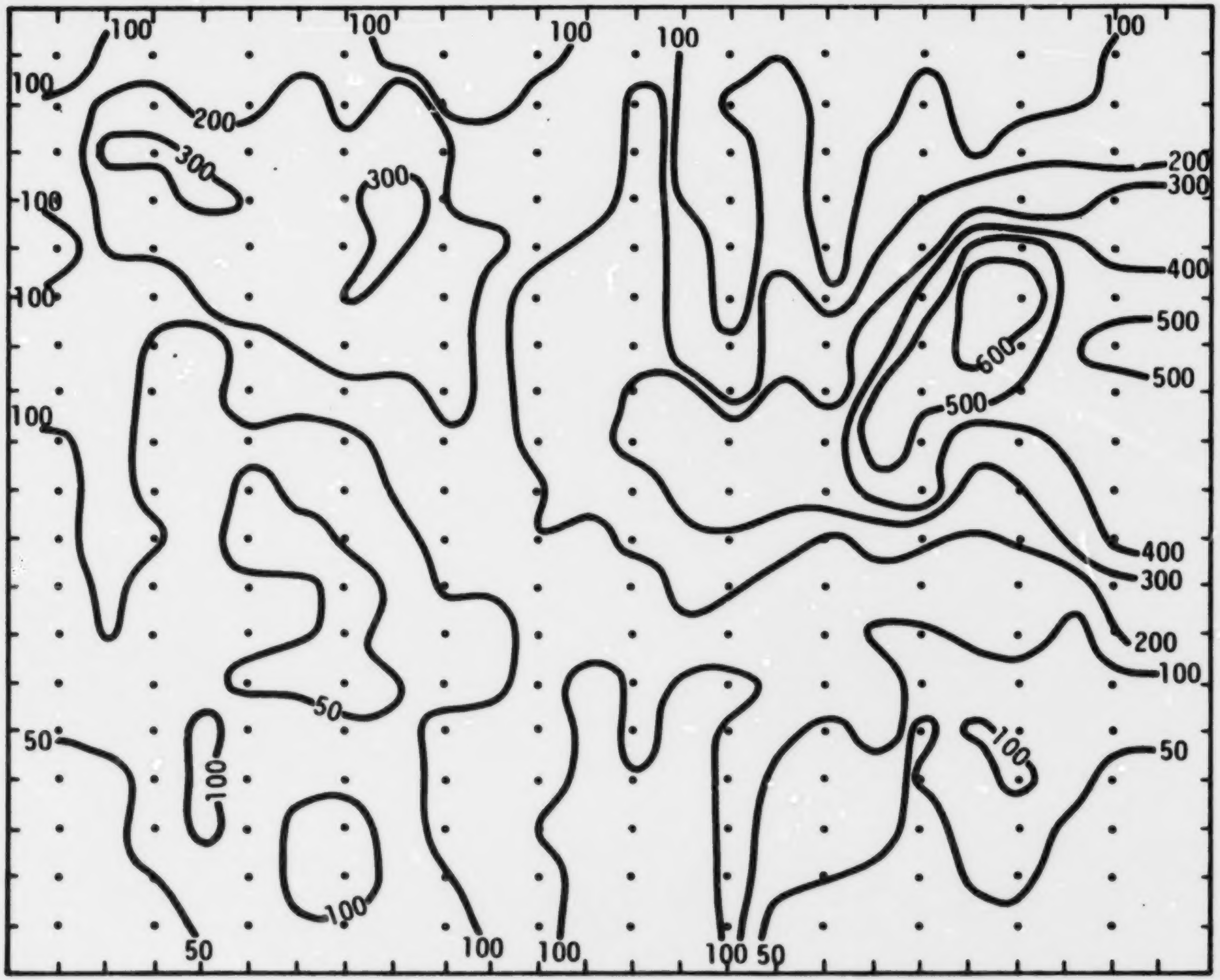

Figure 6-8. Velocity distribution patterns resulting from improper gas distribution. (Numbers are actual values in various portions of the ESP inlet. The average velocity through the unit is 166 ft/min.)

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Wash-out may be required to reveal metal surfaces, and probing may be necessary to determine the extent of deterioration. The service, application, history, and age of the unit will determine the level of detail needed.

The distribution plate should be inspected for wear and deposits. Location of deposits should be noted and correlated with rapper operation to determine what corrective action should be taken. Among the numerous reasons for the pluggage of distribution plates are gas velocity distribution, dust stratification, dust composition, low gas temperature, moisture, or ineffective rapping. When a portion of the plate becomes covered with dust, the resistance to gas flow increases and causes gas flow to shift to cleaner areas. When clean, the distribution plate offers a uniform resistance to flow by evening out the velocity vectors entering the ESP from the duct. Pluggage of the plate starves areas (lanes) of the collector of both particulate and gas flow. The resulting shift in gas flow reduces the physical size of the collector with respect to treated gas volume (i.e., decreases SCA, increases superficial velocity, reduces treatment time, and reduces efficiency). It is critical that the distribution plate be as clean as possible and that effective rapping be maintained to remove accumulated dust.

Most distribution plates are rapped from the upper edge, which is not as effective as horizontal (face) rapping. Changes in rapping direction, frequency, and intensity are often required to remove chronic dust accumulations. A change in rapping direction may necessitate structural changes in the distribution plate supports or an attachment to accommodate the additional stress on the welds.

Severe plate pluggage may result in a gas pressure sufficient to distort and collapse the plate. Figure 6-9 shows a chronic distribution plate pluggage problem that has resulted in reduced efficiency and distortion of the plate into the electrical field.

Dust accumulation in the inlet nozzles can also place abnormal stress on the distribution plate and cause the plate to collapse into the inlet electrical field.

6.3.2 Deposits on Electrodes

The electrode is the electrical component that provides the high electric field in which particles are placed. The electrode generates the corona

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Figure 6-9. Chronic distribution plate pluggage problem.

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that provides electrons, and subsequently, ions for particle charging. The diameter of the electrode or spike is critical in determining the voltage at which corona is initiated. The inspector should visually check the depth, location, and hardness of deposits on wires before and after rapping. An evaluation before rapping indicates areas of close clearance or ineffective rapping. Instead of being uniform along the electrode length, deposits may be heavier near the bottom of the wire or they may occur at the outlet of the electric field (plate bottom). These deposits are commonly referred to as donuts or dumbells. Areas of heavy accumulation can be correlated with electrical power readings (V-I curves) prior to shutdown. Buildup on weights and the lower wire frame should be noted as possible areas of grounds, and the free movement of bottle weights in the weight guides should be checked.

All abnormally heavy deposits should be removed manually before startup. Depending on dust composition and hardness, simple rapping with wood poles may dislodge the deposits. In some cases, dropping a heavy weight with a wire rider (slot) down each wire and retrieving it by rope will remove hard crusty material. Dust deposits on the wires should be evaluated from the lower wire frame area and upper wire frame area.

Bottle weights can be freed in the wire frame guides by striking them with a heavy object (hammer, pipe, etc.). Care must be taken not to dislodge the wire from the bottle weights. Wires are held in place by the weight of the bottle. If the bottle becomes frozen, the wire may partially move out of the seat and later become free during normal rapping. Figure 6-10 shows a heavy accumulation of dust on bottle weights that can reduce clearance and cause eventual grounding of the electrical field.

The inspector should note the location of any wires removed because they were grounded (clipped wires) or those removed because of close clearances. Random removal of up to 10 percent of wires does not reduce ESP efficiency; however, removal of several wires in one lane creates a path through which gas may pass without particle charging. Any areas where a large number of wires have been removed should be investigated.

If an electrical short was identified during the external inspection, the indicated bus section should be checked from the top frame to determine

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Figure 6-10. Example of bottle weight deposits.

if a wire has burned off and is grounded. The grounded wire should be removed.

6.3.3 Plate Deposits

The thickness of dust deposits on collection surfaces should be evaluated to determine if rapping is effective. This evaluation should be made at shutdown, prior to the rapping and/or washout of the ESP. Areas that showed low power levels during the external inspection should be targeted for special analysis.

Because dust removal from plates is not uniform, dust tends to fall in large layers when the plates are rapped. Adherence is a function of dust composition and thickness, plate design, rapping method, rapping intensity and frequency, and electrical field strength.

Dust removal is best at the top of the plate (top rap) and worst at the bottom of the plate. Variations in dust thickness from the top to the bottom are normal and usually should not interfere with collection efficiency.

The resistivity of the dust layer is more important to collection efficiency than its thickness is. Heavy dust deposits of conductive dusts (e.g., those produced by high-sulfur coal) may not reduce power input, but moderate dust layers (less than 1/16 in.) of high-resistivity dusts (e.g., those produced by low-sulfur coal) will severely reduce power input and collection efficiency. Layers of resistive dust are hard to remove by heavy rapping forces, whereas conductive dusts will generally fall off the plates in large sheets. Variations in the thickness of dust deposits from area to area within the collecting fields are an important indicator of potential rapper problems.

6.3.4 Deposits on Wire Frames

Dust accumulations on upper wire frames, plate rapper beams, anvils, and the roof structure should be checked because these accumulations can indicate gas velocity vectors above the collection fields and possible gas sneakage. Figure 6-11 shows an accumulation of dust on the rapper header beams of the upper wire frame. Because of the inlet plenum design, deposits such as these are more likely to occur in the inlet mechanical field, where gas vectors are upward. Heavy deposits can cause electrical grounding of the high-voltage

Figure 6-11. Accumulation of dust on rapper header beams.

frame. They also can add mass to the wire frames and plate system, which tends to dampen rapping energy and reduce rapping effectiveness.

6.3.5 Antisneakage Baffles

Gas baffles between the fields of the ESP prevent flue gases from passing above or below the gas treatment zone. The location and design of these baffles vary with the manufacturer and the age of the unit. In general, however, the baffle is placed between fields at the hopper valleys, at the centerline of hoppers, or between fields in the roof.

In units equipped with hoppers or with drag chains whose movement is perpendicular to the gas flow, the baffle is a fixed sheet of metal. Figure 6-12 shows the location of a hopper centerline baffle. These baffles should be solid partitions with openings only for structural bracing, passage of level detector beams, or maintenance access. The baffle should extend down into the hopper throat to prevent sneakage, but not to the point of interfering with hopper discharge.

In many designs, the baffle (particularly the upper baffle) also serves as a structural support member. Figure 6-13 shows an upper baffle used as a plate suspension.

In drag bottom systems in which the drag moves parallel to the gas flow, baffling is critical to the prevention of gas sneakage below the treatment zone. The baffle must be free to move out of the path of the drag scraper blades (top and bottom) and must have penetration points for the drag chains. Over years of operation, the baffle plate may become distorted, misaligned, and shifted into a deflected position. Baffle plates also may be torn by the scraper blades and have to be removed from the unit. Figure 6-14 shows a scraper blade passing under a baffle in the deflected position.

The inspector should verify that all baffles are in their proper position and free to move and that baffle sections do not interfere with each other during motion. Movement of baffles during chain drag operation should be checked from outside of the ESP. A visual evaluation can be made through the access door or from structural walkways between fields above the drag area. The inspector must not enter the hopper when drags are in operation.

As a means of avoiding complete loss of resistance to gas flow under the fields, the spacing of the drag chain blades is set to prevent successive

Figure 6-12. Baffle hopper centerline.

Figure 6-13. Upper baffle used as plate suspension.

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Figure 6-14. Scrapper blade passing under a baffle in a deflected position.

baffles from being deflected by the scraper blades. As drag chain blades and chains are replaced during maintenance and repair, the position of blades may change, which can result in simultaneous deflection of the baffles. Adjacent parallel drags should be offset to minimize the baffle opening at any instant. The inspector should check the sequencing of baffle operation from the outside access door.

Failure to maintain positive baffling can allow flue gas to pass under the treatment field and result in the reentrainment of particulate matter into the outlet plenum. Because dust is stripped from hoppers during rapping, sneakage generally increases the severity of rapper spikes. These spikes are most severe when the unit is operated above design gas volumes (higher velocity), when the top inlet is used and gas distribution is poor, or when the vector of the gas entering the unit is downward into the inlet hopper.

6.3.6 Drag Chains

Drag chains remove the dust as it is rapped from the collection plate surfaces. These drags may be perpendicular or parallel to gas flow, and they operate on a large chain sproket (head and tail) that allows them to pass over the ESP bottom and then return in the opposite direction (Figure 6-15). Attached to each pair of chains are drag scrapers (L-shaped plates) that push the dust to the end of the chain and discharge it into a transversely mounted screw conveyor.

To be effective, movement of the drag scrapers must be parallel to the hopper bottom and not be deflected upward (which causes the scraper to pass over the dust layer). Deflection can be prevented by adjusting the chain drive sprocket pillow blocks to maintain chain tension.

Each chain must be parallel to the other, and the tension must be identical. Misalignment can cause chains to break or bind and/or the dust to shift to one side during operation.

The drive shaft is usually equipped with shear pins to prevent major damage if the drag chain should become entangled in the baffles, with other chains, or with the bottle weights.

Because of the possibility of binding, drag chain scrapers are separated from each other and from the wall surfaces. This clearance can result in an

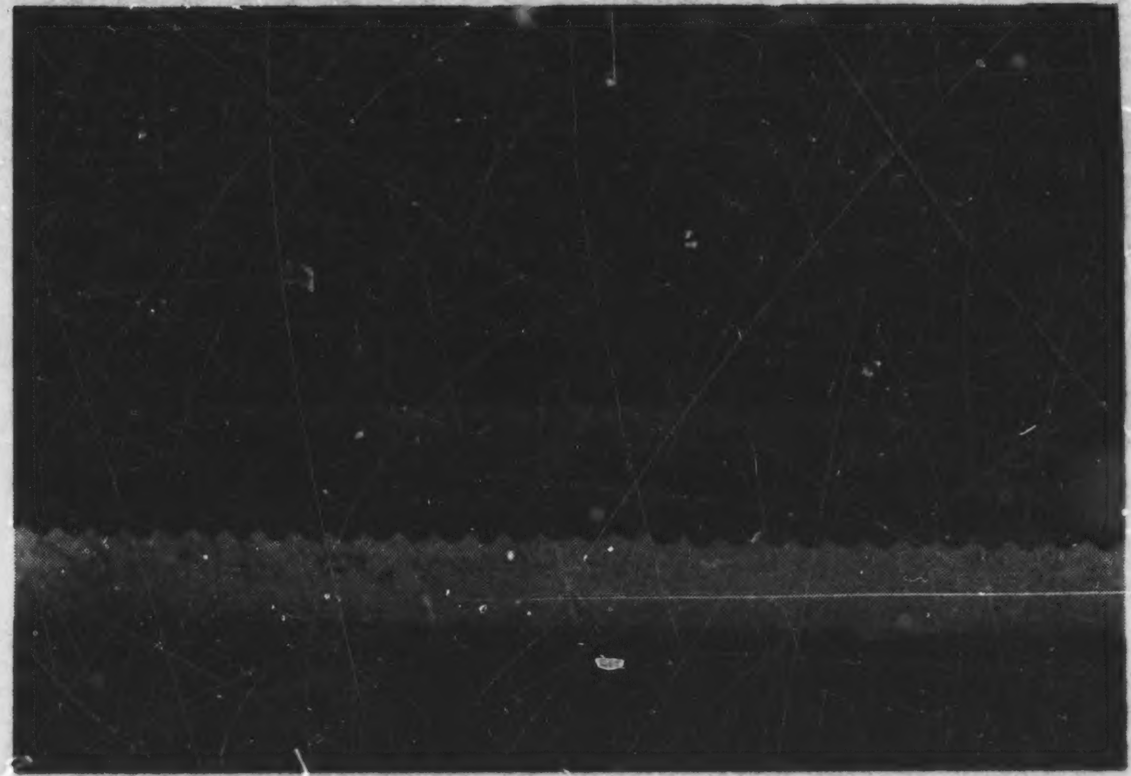

Figure 6-15. Drag chain assembly.

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accumulation of deposits that may eventually interfere with electrical clearances and cause grounds. The inspector should note the location of any such deposits, and these should be removed periodically as a preventive maintenance measure.

Drag chains are considered to be the highest maintenance item in an ESP. Any deviation from optimum operation can result in extensive downtime for repair and maintenance.

6.3.7 Penthouse and Insulator Enclosures

The penthouse is located between the weather enclosure (roof) on which the rapper and T-R sets are located and the inner roof containing the flue gases. This area contains the support (barrel) insulators that are used to hang the electrical wire frames; it does not contain flue gases, and it is pressurized to prevent dust penetration through rapper access openings and insulators.

The inspector should determine whether dust is entering the enclosure, and if so, the probable point of entry. Dust deposits can cause electrical tracking and surface cracking on insulators. Penetration can be expected if the penthouse purge fans were ineffective or were not operating during the external inspection. The inspector should also check for any areas of corrosion or any indications of water flow from condensation or rain penetration.

The insulators should be checked for signs of condensation, cracks, dust deposits, or chips on the upper edge. If insulator heaters were not operating during the external inspection, continuity checks should be made of the heating elements.

Condensation is the result of hot, moist gases contacting colder surfaces. The problems described in this section are related to the paper industry where the high-power usage for heated air is accepted by the industry as a necessary cost of operation. The underside of the penthouse roof and external penthouse sides are insulated. The bus ducts must also be insulated. The penthouse is pressurized and insulators purged with heated air. This requires 5.5 kW and 100 cfm per insulator. Failure of the heaters results in cooling of the hot roof in contact with the process gases. Corrosion and dust in the penthouse is indication of a failure of the pressurizing fan.

A more cost-effective means used on other dry-dust applications such as incinerators, industrial power boilers, cement, lime, etc. will insulate the top surface of the hot roof and external penthouse sides. The cold penthouse roof and bus ducts are not insulated. The insulator surfaces are maintained above outside ambient by radiation from the process and a 400-watt contact heater. The penthouse is pressurized with ambient air at the rate of 100 cfm per insulator. With all internal surfaces above ambient, condensation will not form. Corrosion and dust buildup in the penthouse are an indication of reverse flow of process gases into the penthouse due to pressurizing fan failure.

If the underside of the weather roof is insulated, blocks of insulation that become loose and fall can create cold spots; these areas should be repaired. The conduit duct from the T-R set to the penthouse may be vented through the penthouse fans and insulated (if the roof is insulated) to keep the temperature of the duct above the condensation point. In some cases, however, the duct is neither insulated nor purged, which results in a cold spot in the roof. Water may condense, run down the sides of the conduit, and cause insulator arcing and failure. In these areas, rapid metal corrosion can occur from the inside of the conduit. Figure 6-16 shows water patterns caused by cold conduit in the penthouse roof.

The introduction of purge air into the penthouse can cause erosion and/or corrosion of the metal in the inner roof below the inlet of the purge air. This area should be inspected for metal thinning, and repairs should be made as necessary. Impingement baffles may be required for adequate distribution of the purge air.

Penetration openings (pipe nipples) of the plate rapper shafts should be inspected for dust accumulation and shaft binding. Deposits should be cleared, and the opening should be sealed with high-temperature rapper boots.

Any major misalignment of rapper shafts through the weather roof to the inner roof should be noted. Major lateral movement can indicate changes in plate alignment and result in possible rapper shaft or anvil failure.

Discharge frame rapper shaft insulators should be checked for cracks and evidence of electrical tracking. Ceramic insulators should be inspected to

Figure 6-16. Water patterns caused by cold conduit in the penthouse roof.

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ensure that end caps are bonded and not loose, and resin-type insulators with tapered connections should be checked for tightness (Figure 6-17), as any loosening of the connection can result in incomplete rapping energy transfer (bouncing).

An insulator compartment may be used when the design does not include a full penthouse. These compartments are referred to by various names, including "coffin box" or "dog houses." Access into these enclosures is limited, and the inspector may need to use small mirrors to inspect areas of the insulators. The compartment should be free of dust and the insulators should be clean as shown in Figure 6-18. Because of the small volume of air required, purging can be effective and complete. Figure 6-19, however, illustrates dust deposits in an insulator compartment.

6.3.8 Rapper Shafts and Anvils

Rapper shafts and anvils that are attached to the collection plate header beam should be inspected for tightness and possible weld failure. For a complete inspection in this area, the surfaces may have to be washed to remove dust deposits; however, washing should be avoided whenever possible to reduce corrosion.

Bolted and welded components of the plate rapping header assembly should be inspected periodically to ensure proper transmission of rapping energy.

6.3.9 Plate Warpage and Cracks

Heavy rapping forces can cause structural failure in some systems because of weld breaks in the plate header support and roof structure, chips in the plate attachment, and channels or splits in the plates (Figure 6-20). After a wash-down, the inspector should inspect the plate support and attachment hardware for misalignment, distortion, or breakage.

Strengthening of the hardware may be necessary if intense rapping forces are required to remove resistive ash or sticky salt cake. Depending on manufacturer, the failure can result in alignment changes or plate dropping, bowing, lateral movement, or tears.

If the unit has been subjected to high temperature, fire, or explosion, plates can become warped, which reduces electrical clearances between plates and wires. This limits the voltage at which flash-over occurs and reduces

Figure 6-17. Resin-type insulator.

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Figure 6-18. Access to a typical insulator enclosure and support insulator for the discharge wire frame.

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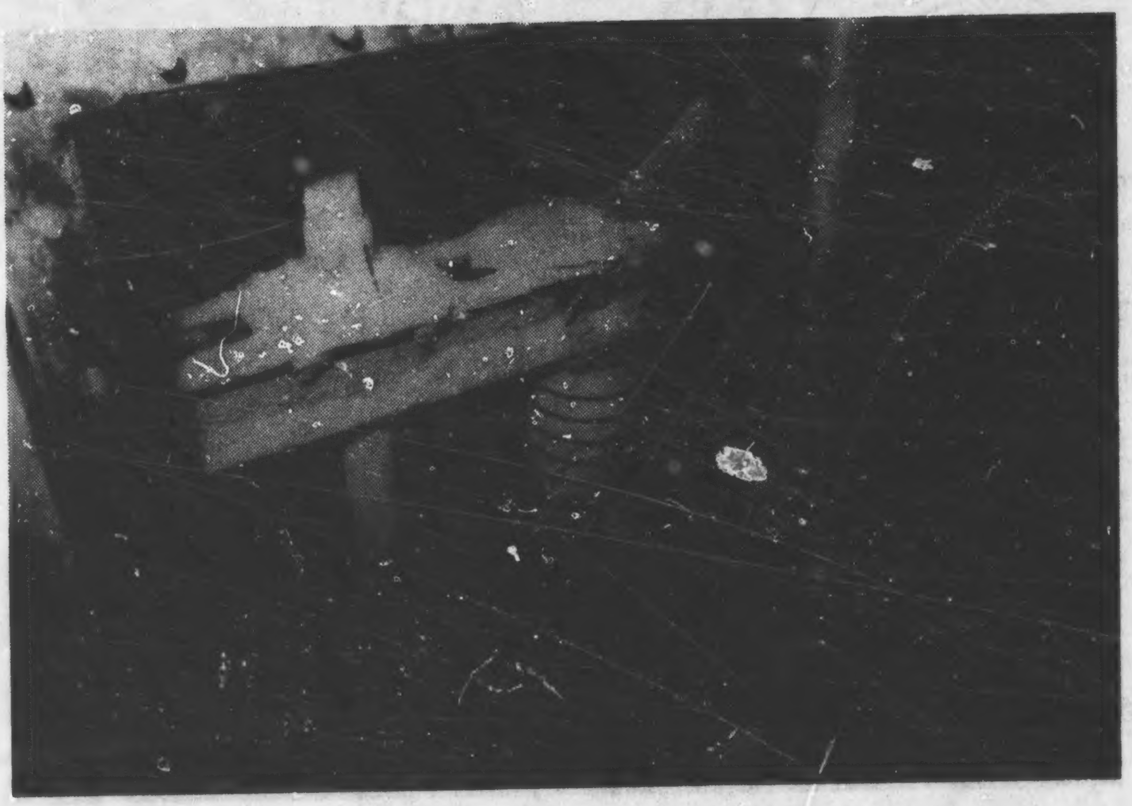

Figure 6-19. Insulator compartment showing dust deposits.

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Figure 6-20. Example of plate cracks.

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total power input to the entire electrical field. Local areas of plate warpage should be identified and the plates should be straightened or replaced. Correction methods include stiffeners, heat treatment, patching, or replacement.

If the ESP has sufficient redundancy, the wires in the area of the warpage may be removed to reduce the clearance problem. This allows electrical power in the field to be increased to normal levels.

Allowable deviation from the plate design is ±1/16 inch. Normally, plate warpage of less than 1/2 inch cannot be detected visually. Visual inspection usually is conducted from the upper wire frame, looking down on the plate and wire. Distances between wire and adjacent plates are compared at several points along the wire length to judge areas of distortion.

Bus section V-I curves (air load) are useful for limiting the areas requiring visual inspection. Because the V-I curve can show misalignment, frame clearance problems, and other factors, a process of elimination may be required.

6.3.10 Antisway Insulators

Several methods are used to support and align the lower wire frame. If the wire frame is supported by pipes attached to the upper frame, squareness of the frame and support pipes must be maintained to enable alignment of the plate and wire system. The wire frame is aligned during installation of the system, and the components are bolted and welded to a ±1/8-inch tolerance. Under normal operation, the wire frame subassembly does not change shape, but the frame may change orientation with respect to the plates and box as a unit. This is covered under plate alignment. Also, excessive force from an explosion or fire can distort the frame.

Many systems allow partial support and alignment of the lower wire frame separate from the upper wire frame. These systems are more susceptible to lower wire frame movement independent of the upper wire frame. Stand-off or antisway devices are used between the wire frame and ESP shell to maintain alignment. Because the wire frame is maintained at high voltage, the antisway devices must be nonconductive. The insulators may be constructed of resin, ceramic, or alumina, and they may be attached to the side wall (horizontal) or to the hopper wall (vertical).

In wire-frame systems, alignment rakes may be used at the leading and trailing edges of the frames, and stand-off insulators may be attached to the alignment rakes. Examples of alignment values and stand-off insulators are presented in Figure 6-21.

If abnormal movement of the lower frames or rakes results from hopper overflow, drag chain breaks, or overheating of the unit, the insulation may be stressed to the point of failure. The inspector should check the integrity and relative position of all insulators.

The attachment of the insulator mounting hardware cannot be rigid; it must be free to move with thermal expansion of the shell and wire frame system. Also, insulators must be relatively free of dust, moisture, and coatings that make them conductive. Electrical tracking can cause insulator failure or grounding of the electrical frame. The inspector should check all insulators for dust deposits and clean each insulator with a nonorganic cleaner.

6.3.11 Falling-Hammer Rappers

Falling-hammer rappers are used to dislodge dust from the plate and wire frames. Each hammer impacts the surface once during the shaft's rotation. Multiple hammers are attached to the shaft with U-bolts and clamps. As the hammer reaches the apex of the shaft rotation, it swings and free-falls in an arc, striking an anvil attached to the wire frame or plates (Figure 6-22).

If the hammers become loose on the shaft, they will not rotate and rapping ceases. The inspector should note any free hanging or missing hammers. Hammers and anvils can also become misaligned, which results in a hammer strike that is offcenter. This can shear both hammers and anvils and cause abnormal wear. Each hammer/anvil pair should be inspected for wear. Anvils can also become detached from the plate and wire frame rakes, which results in poor rapping.

6.3.12 Plate and Wire Alignment

For practical purposes, the collection plates in each collection field should be vertical and parallel to the ESP walls. Each plate pair forms a gas lane in which particle charging and collection occurs.

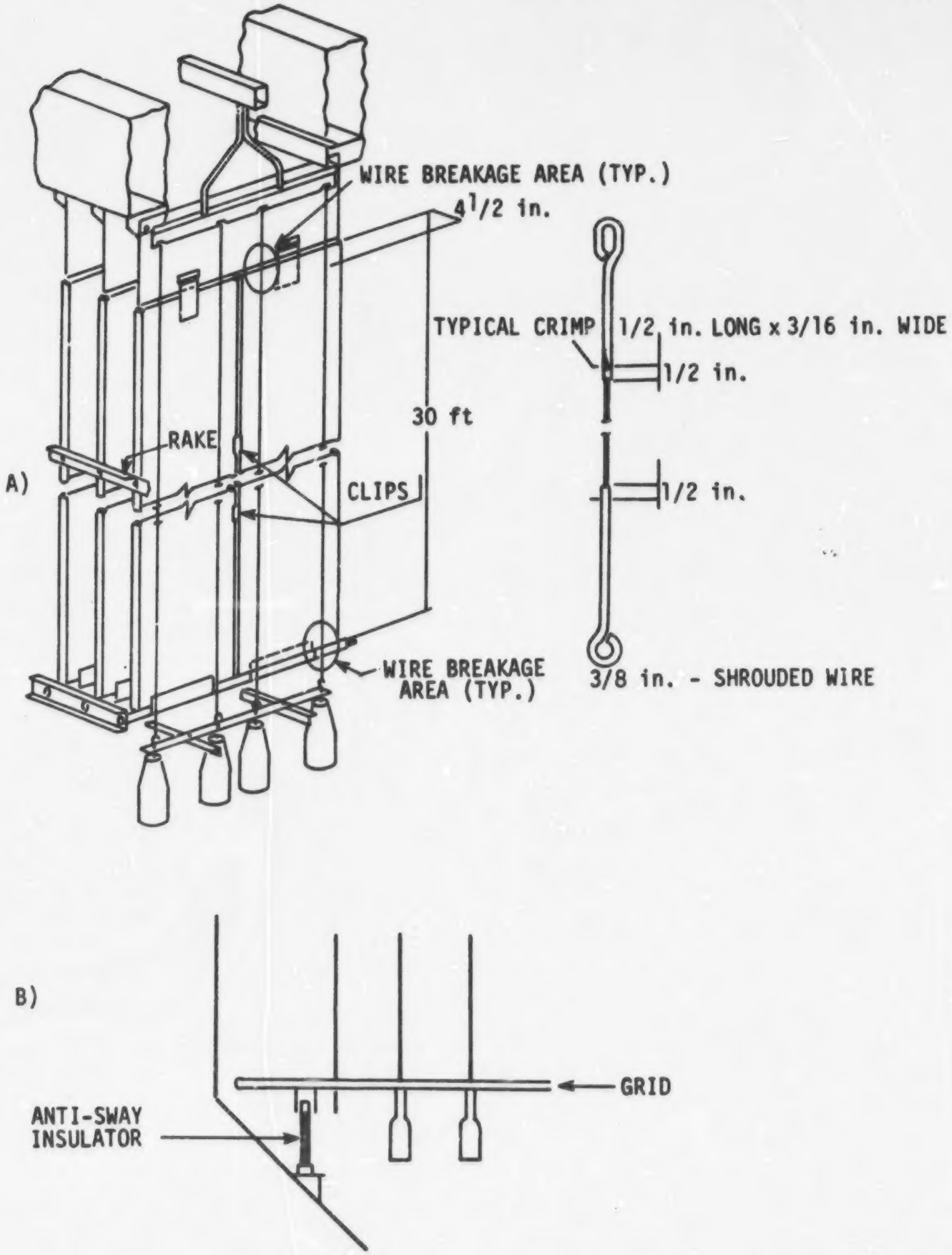

Figure 6-21. Examples of a) alignment rake and b) anti-sway (standoff) insulator.

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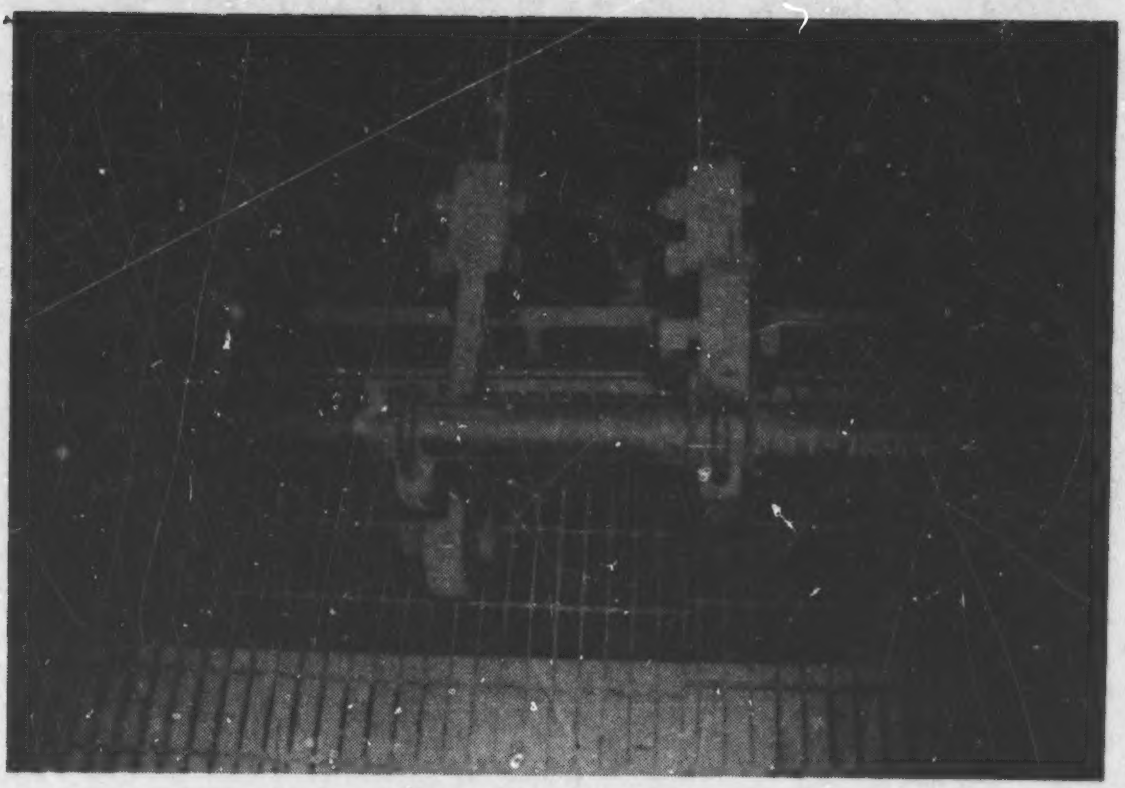

Figure 6-22. Falling hammer rapper.

Each electrode must be centered in the gas lane and be parallel to the plate surface. Because the plate and electrode systems are independently positioned and supported in the field and cannot make contact, each system must be aligned accurately. Any reduction in clearance between a grounded surface (plate, stiffener, brace, alignment bar, etc.) will result in a lower spark-over voltage and current. Figure 6-23 shows a broken plate stabilizing bracket, which could result in reduced clearance between the wire and plate frames. This reduction in current limits power input and collection efficiency. The normal accepted tolerance between wire and plate is ±1/4 inch.

If the plate system is assumed to be parallel to the shell and to serve as a fixed reference, the upper and lower wire frame can then be shifted to the center of the wires between the plates. Normally, the upper wire frame is supported and hung from four or more support insulators, each of which can be adjusted.

In general, each wire frame can move in two rectilinear directions (perpendicular and parallel to the gas stream) and can rotate through a limited arc around a vertical line (movement is lateral around the set of supports). Rotation of the frame about a horizontal line can occur if the upper frame is not level. A 1/16-inch change in elevation can be magnified to an approximate 1/2-inch movement of the lower frame in the lateral direction over the length of a 30-foot plate.

Either the lower or upper frame in the direction of gas flow may cause close clearances to occur at the edge of the plate near the stiffeners or alignment rakes (Figure 6-24).

Independent movement of either the upper or lower frame perpendicular to gas flow may cause close tolerances to occur at each plate edge, either entering or exiting the plate area (Figure 6-25).

Movement of both frames perpendicular to gas flow can create a clearance problem along the total length of the wire (Figure 6-26).

A shift of two of the support insulators perpendicular to the gas stream can cause the wire frame to rotate and result in close clearances at the corner electrode of each wire frame (Figure 6-27).

Figure 6-23. Photograph of broken plate stabilizing bracket.

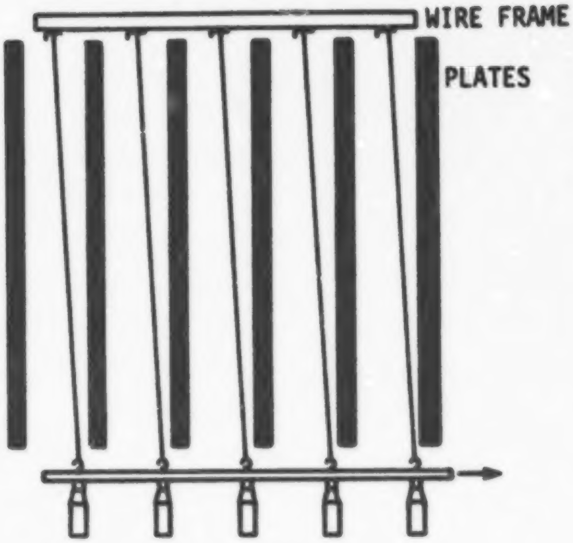

Figure 6-24. Lateral movement of upper or lower wire frame (end elevation view).

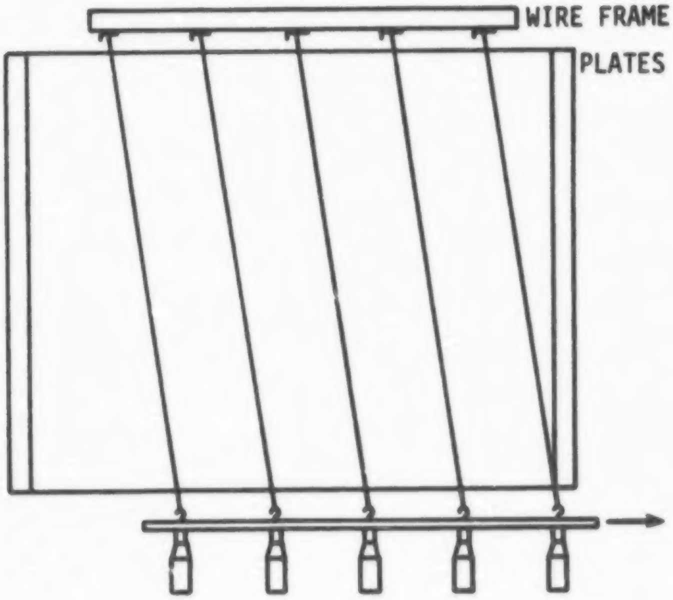

Figure 6-25. Longitudinal movement of upper or lower wire frame (side elevation view).

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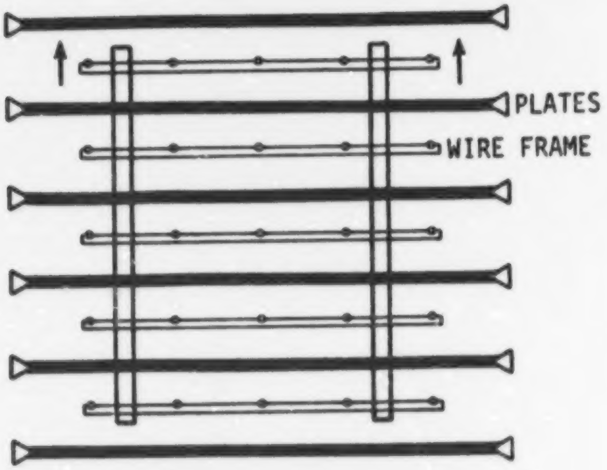

Figure 6-26. Lateral movement of upper or lower wire frame (plan view).

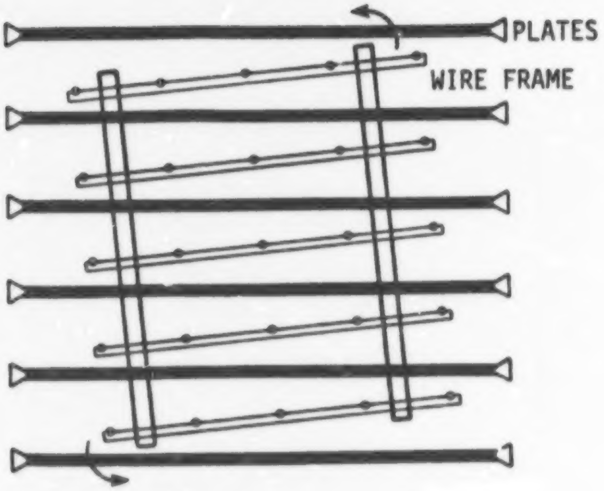

Figure 6-27. Rotation of upper or lower wire frame (plan view).

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Distortion of the insulator support seat (inner roof) can allow one or more of the corners of the wire frame to move downward and cause close clearance problems in the area diagonally opposite the insulator at the lower wire frame.

Changes in alignment are made by moving the support insulators (singly or in pairs) laterally or perpendicularly to the gas stream, depending on the nature of the alignment problem. Frame elevation is changed by moving support adjustment screws or other devices (shims, washers, etc.). Figure 6-28 shows jack screws used to move the insulator horizontally and the screw and nut used to move the frame vertically.

The inspector should check wire-to-plate clearances visually at each corner of the lower and upper wire grid (eight points). The direction of the close clearance at each point will determine how the wire frames should be moved. Any field with alignment problems may be correlated with corona power readings determined during external inspections. Accurate realignment of the wire frame should be accomplished by using a notched alignment scale or spacer (Figure 6-29).

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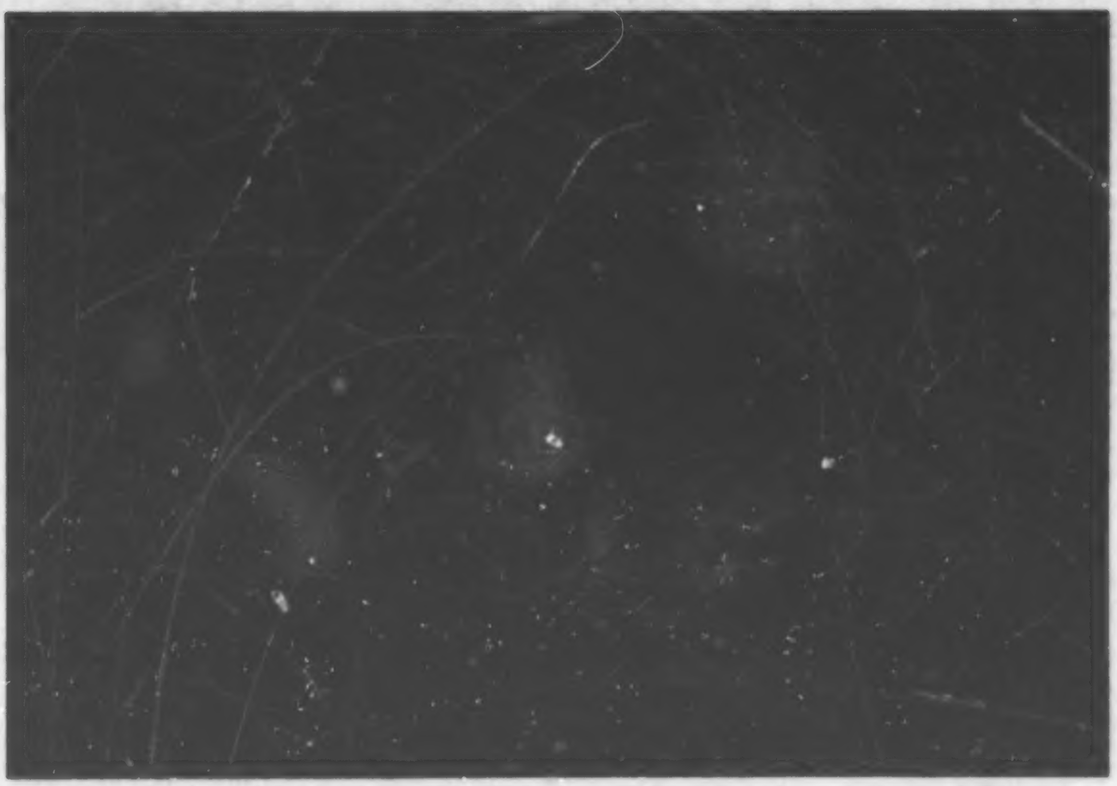

Figure 6-28. Jack screws.

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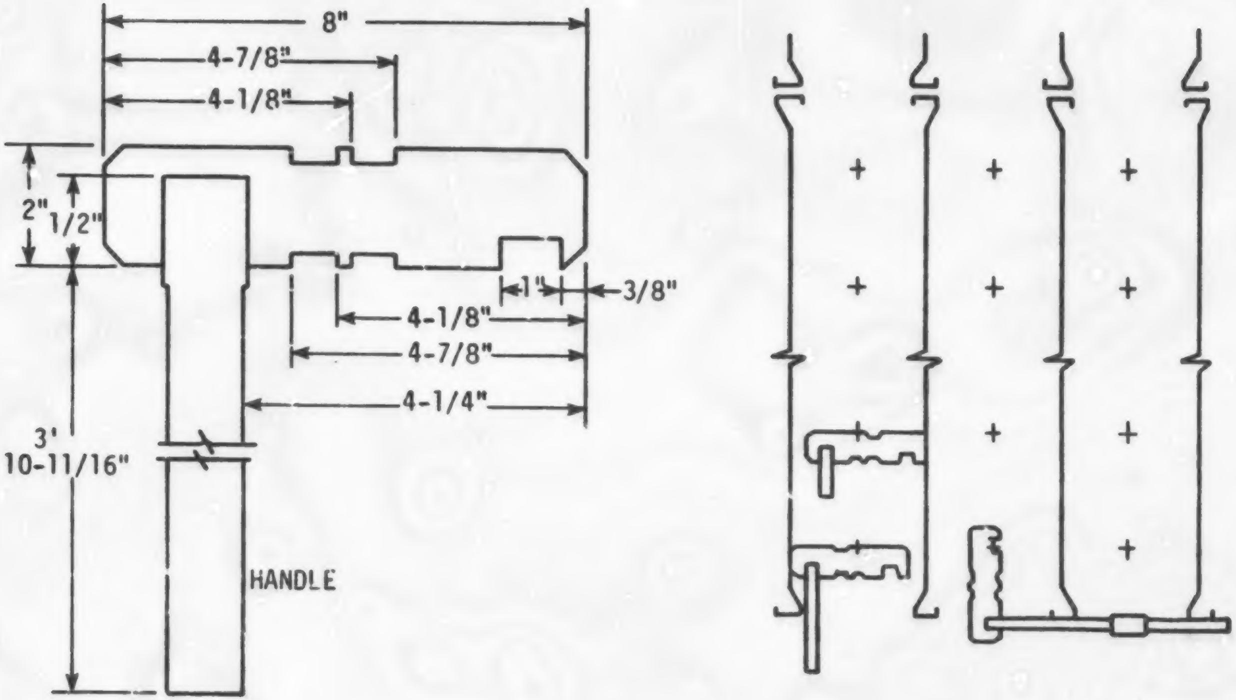

Figure 6-29. Notched alignment spacer.

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2. Industrial Gas Cleaning Institute Gas Flow Model Studies. Publication EP-7.

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SECTION 7

SAFETY

The safety of plant personnel during all aspects of ESP operation and maintenance and Agency personnel during inspections is of ultimate importance. Areas of concern include electrical shock hazard, confined area entry (oxygen deficiency and toxic gases), hazardous materials (dust, metals, etc.), chemical burns, eye injury, and normal industrial safety concerns such as moving equipment, falls, etc. In ESP's, many of these concerns are simultaneous and can result in potentially serious injuries to personnel. With proper planning, safety equipment, and established procedures, operation and maintenance and inspections can be performed safely without risk of injury.

Many of the potential hazards and proper procedures for addressing them are discussed in the following subsections. Further information on confined-area entry and manufacturers of safety appliances can be found in specific vendor maintenance manuals on installed units, Occupational Safety and Health Administration (OSHA) publications, and National Institute of Occupational Safety and Health (NIOSH) publications.

7.1 ELECTRICAL HAZARDS

Electrical shock is the greatest concern in the operation of an ESP. During the particle-charging process, high direct-current voltages are generated by the T-R set and transferred to the discharge electrodes. All portions of the electrical system outside of the ESP shell must be insulated or isolated from potential contact. All access points to the electrical distribution system must be closed and bolted or key-interlocked to limit inadvertent access to the system. In addition, a clear, legible sign must be attached to each component indicating the nature of the hazard (i.e., extremely dangerous high voltage). Areas requiring warning signs include (but are not limited to) T-R set control cabinets, high-voltage conduit, the T-R set, shell access

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doors (inlet/outlet plenems, top access doors, insulator compartments, and penthouse), hopper access doors, and rapper control cabinets.

Key interlocks are used to assure that the ESP has been deenergized before personnel enter the ESP or electrical distribution system. The key-interlock system consists of the use of keys in a number of sequenced steps that must be followed to deenergize and permit ESP components to be opened. Each interlock system is especially designed and installed for each unit, and the procedure and equipment can be expected to vary from unit to unit. For specific instructions, the inspector should refer to the manufacturer's literature.

Most key-interlock systems begin with the main circuit breakers on the T-R set control panels. Opening the circuit breakers releases a mechanical interlock that allows keys contained in the circuit breaker mechanism to be rotated and removed. (See Figure 7-1.) Rotation of the keys locks the breaker in the open position and prevents its operation. One key is released for each T-R set control cabinet.

The keys from the control cabinet are inserted into the interlock on the T-R set grounding switches; one key is used for each T-R set. (See Figure 7-2.) Insertion of the key and rotation allows the T-R set grounding switch to be moved from the operation (closed position) to a ground position. The switch cannot normally be interlocked in an open position; it must be fully closed to a ground position, which completes the electrical circuit from the deenergized transformer to ground. This position ensures safety by 1) disconnecting the T-R set from the electrical distribution system, and 2) grounding the T-R set. Any attempt to energize the T-R set would result in an immediate short circuit to ground.

When the T-R set ground switch has been positioned, a second set of keys located on the T-R set ground switch may be rotated, which locks the switch in position. Removal of these keys ensures that the switch cannot be moved into the open or operating position.

Keys from the T-R set ground switch may be placed into the master key interlocks in the transfer block. After keys from all ground switches are in place, keys located in the transfer block can be rotated. Rotation of these keys locks the T-R set switch keys in place and prevents their removal. The transfer block keys may be removed and used to open access doors on the ESP.

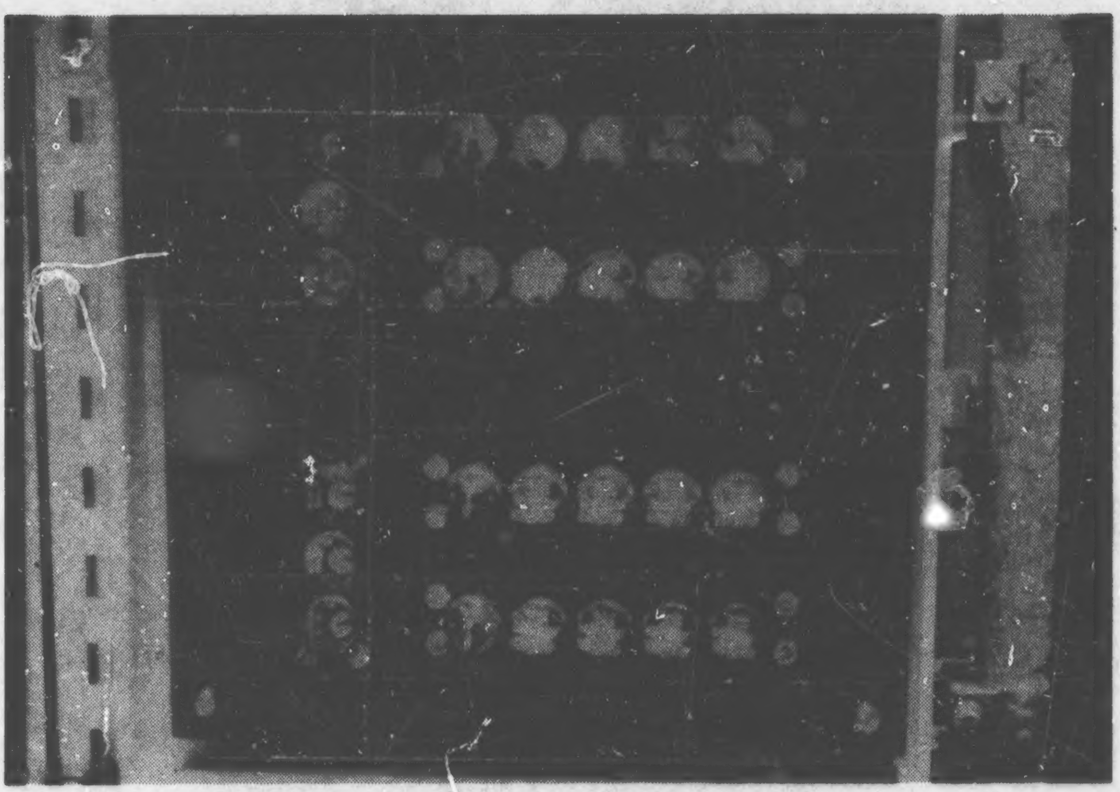

Figure 7-1. Control cabinet key interlocks.

Figure 7-2. T-R set ground switch key interlocks.

The number of keys needed depends on the number of T-R sets and access doors on the individual units. Maintenance of the key-interlock system is critical in any safety program. Locks are equipped with weather-tight covers (caps, lock boxes, etc.), and each cover must be replaced after removal and maintained in that position. Locks should be lubricated (graphite only, no oils), and preventive maintenance should be performed as necessary to ensure clean, trouble-free operation.

Under no circumstances should the key-interlock system be bypassed or short-circuited to gain access to the ESP without proper and complete deenergization of the unit. If special studies or analyses require access to an energized unit, a complete safety analysis, including proper safety procedures, must be established for each occurrence.

Following the key-interlock procedure provides two points of electrical safety: 1) the T-R set main breaker (mechanical lockout), and 2) the T-R set ground switch (electrical isolation and ground). Many companies further isolate the unit for positive assurance of grounding of the electrical distribution system. Access doors are removed from the electrical conduit between the T-R set and wire frame, and the lead wires are disconnected from the wire frame.

A potential for nonisolation of the T-R set ground switch exists in many older designs that use an immersed switch in the transformer fluids. In these designs, the switch arm mechanically connected to the knife switch with set screws, clamps, etc. can become loosened with use and will not close fully. Because the switch is not visible, its position cannot be verified. As a further safety measure, many companies use a permanent ground switch or wire that must be thrown or placed in position on the high-voltage bushing in the penthouse or insulation enclosure before further access is possible. Placement of this device on an energized T-R results in an immediate short and a T-R trip.

More modern designs require an air switch on the T-R set, and the contacts are visible through a window. This ensures that the T-R is grounded and allows visual verification of the switch position.

Grounding straps bolted to the ESP shell must be provided at each access point to prevent potential electrical hazards. The strap is attached to the electrical discharge system nearest the entry point and clamped in place

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prior to entry. (See Figure 7-3.) The corona wire-plate system acts like a capacitor and discharges slowly after a T-R set trip. To prevent potential shock, the ground strap should be connected to the plate system and discharge electrode system.

Ground straps should be checked routinely to ensure their continuity, and the insulated attachment devices (fiberglass or wooden handles) should be inspected for damage. If exposed to weather, wooden handles can deteriorate; and if exposed to dust and metal particles, they can become conductive because the dust and metal particles become imbedded in the surface.

Although rare, it is possible to lock up and energize an ESP with personnel inside. The design of the key-interlock system only requires the following of a step-by-step procedure to energize a unit. To prevent the possible closure of the unit with personnel inside, a tag or personnel lock system is required. Central Operation should be notified whenever anyone enters the unit. Tags should be placed on the main breaker, T-R set switch, and entry door advising that men are working inside. Entry should never be made alone without proper notification and proper tagging of the access door. If a procedure is established for use of a two-man buddy system (one man on the outside), that person cannot leave this position without being replaced.

7.2 HOPPER ENTRY

Hoppers present special safety hazards. Although access to an ESP hopper does not put one in direct contact with the electrical system, a broken electrode (wire) represents a potential electrical shock hazard.

It is generally recommended that hopper doors be interlocked and that the doors be opened only after the unit has been deenergized. For economic reasons, however, many companies use padlocks instead of a key-interlock system. In principle, this practice is as safe as the key-interlock system if proper safety procedures are followed. Workers, however, tend to remove the lock and open hopper doors prematurely to cool a unit quickly or to clear a hopper pluggage. The danger created by opening the doors is not so much one of electrical hazard as the discharge of hot ash impounded in the hopper.

In the opening of hopper doors, the inspectors must take care to ensure that no accumulation of collected dust is impounded behind the inner door.

Figure 7-3. Ground clips.

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Before hopper doors are opened, an internal inspection also must be made from the top of the collecting surfaces to be certain no buildup is present in the corners of the unit or in the valleys of pyramidal hoppers. Dust that has accumulated in valleys or corners may break loose during entry into the hopper and cause minor injury. In some cases, more serious injury or suffocation can result from dust falling on the inspector and possibly burying him. If lower side access doors are available and catwalks (beams, etc.) are provided between fields, an inspection should be made from the lower level.

Entry into hoppers for purposes other than maintenance should be avoided. Maintenance first should be attempted from outside of the hopper. If the hopper must be entered, steps should be taken to dislodge and discharge dust before such entry. This can be accomplished by mechanical vibration (vibrators, hammers, etc.), poking, prodding, or air lancing. Complete removal can be accomplished by washing with a high-pressure water hose.

Removal of accumulated dust should be made from the lower catwalk at the bottom of the ESP; it must not be attempted from inside the hopper. Care should be taken to ensure that any dust accumulation in the inlet and outlet plenums (nozzles) is removed. This material can become dislodged, move en masse into the inlet or outlet field hoppers, and completely fill the hopper. Finally, before the hopper doors are opened, the inlet plenum should be checked, and any dust should be moved into the hopper for discharge.

Hopper doors should not be opened during ESP operation because hot ash could overflow onto the operator. This ash is very fluid, and it can quickly engulf and severely burn a person. Even after prolonged storage, ash temperatures can be 300° to 400°F in cold-side ESP's and 700° to 800°F in hot-side units.

All hopper doors should be equipped with safety chains or double latches to prevent complete opening upon release. This can slow the loss of ash in the event of accidental opening of a full hopper.

Most hopper inner doors have design features that, if properly used, will ensure that no door is opened when dust is impounded behind it. First, a pipe coupling with plug that can be removed should be installed in the door; this would allow visual verification. Second, a pressure-type latch should be used that allows a portion of the door seal to be released to create a gap between the door and sealing jam. This partial release would allow accumulated dust to flow out and indicate a partially full hopper without the possibility of the door opening fully.

A normal practice calls for full discharge of the hoppers before entry and after each period of dust removal. A full hopper may be determined by striking the door with a hammer. If the hopper is empty, this will produce a resounding ring, indicating there is nothing against the inside surface; if the hopper is full, the blow will produce a dull thud.

A further warning regarding hopper entry involves the use of handgrips, footholds, etc. in the hopper. Because of the possible dust buildup on protruding objects, manufacturers have purposely avoided the use of handholds and footholds in hopper interiors. The steep valley angles and dust layer create a potential for a fall and injury for persons entering the door. Because of the angles and small door openings, back injuries are the most common injury other than abrasions. Outside access equipment (scaffolds, ladder, handholds, etc.) should be installed to minimize the awkwardness of hopper-door entry. Installing handholds inside the hopper is also helpful.

If nuclear hopper level detectors are used, the radiation source (beam) should be shielded from the outside prior to entry. This shielding should be part of the interlock system for the doors.

Hopper evacuation systems (screws, drag chains, agitators, etc.) should not be operated when personnel are inside the hopper area or in an area from which they could fall into the hoppers. Dust accumulation that is discharged into the hopper can be considered a line bottom with moving equipment. The dust becomes fluid and results in a nonsolid footing. Scaffolds on which personnel may be standing can shift and float, and persons inside could become engulfed in the fluidized ash.

7.3 CONFINED-AREA ENTRY

A confined space is an enclosure in which dangerous air contamination cannot be prevented or removed by natural ventilation through opening of the space. Access to the enclosed area also may be restricted so that it is difficult for personnel to escape or be rescued. The most common examples of confined spaces are storage tanks, tank cars, or vats. Depressed areas (e.g., trenches, sumps, wells) also may have poor ventilation and considered confined spaces. An ESP falls under the general definition of confined space, and as such, requires special procedures and precautions with regard to entry.

Potential dangers presented by confined space fall into three categories: oxygen deficiency, explosion, and exposure to toxic chemicals and agents. Anyone entering the ESP for inspection or maintenance must assess the risks and potential dangers and follow specific safety requirements for each category.

7.3.1 Oxygen Deficiency

Oxygen deficiency is the most common hazard. Any gas introduced into a confined space displaces the atmosphere and reduces the oxygen content below the normal value of 20.8 percent. Out-gassing of combustible gases (methane, H_2S, organic vapors, etc.) from collected particulate can result in local pockets with reduced oxygen levels. Further, application of the ESP to combustion sources (e.g., utility boilers, industrial boilers, cement kilns, recovery boilers, incinerators,) produces an atmosphere that is extremely low in oxygen content (2 to 10 percent). Purging of the unit during cooling does not always completely replace the flue gases with ambient air, and local pockets may remain.

Reduction in oxygen pressure below normal conditions has increasingly severe effects and eventually leads to death. Oxygen levels of less than 16.5 percent result in rapid disability and death. Table 7-1 shows the effects of reduced oxygen concentrations for various lengths of time. Because of the subtle effects of oxygen deficiency, the average person does not recognize the symptoms and may ignore the danger. By the time the person does recognize the problem, he may no longer be able to remove himself from the dangerous environment.

7.3.2 Explosion

Explosive atmospheres can be created in confined spaces by the evaporation of volatile components or improper purging of the ESP when the process is shut down. Three elements are necessary to initiate an explosion: oxygen, a flammable gas or vapor, and an ignition source. A flammable atmosphere is defined as one in which a gas concentration is between two extremes: 1) the lower explosive limit (LEL) and the upper explosive limit (UEL). A mixture of gas and oxygen in a concentration between these two values can explode if a source of ignition is present. With regard to ESP inspection and maintenance, explosive gases normally consist of methane, hydrogen, carbon monoxide (CO), and mixed organic vapors. The gases most commonly present at ESP shutdown are CO and methane.

Possible sources of ignition include cigarettes, matches, welding, cutting torches, and grinding equipment. Sparks can also be generated by static electricity and electrical discharge through grounding straps. The best means of preventing explosion is to dilute the flammable gas below the LEL by ventilation. It is not safe to assume that a source of ignition can be eliminated and to allow work to continue in a potentially explosive atmosphere.

Work in a confined area may release flammable gases that, once released, can increase in concentration. Constant ventilation should be provided to maintain the concentration below the LEL.

Because many vapors are heavier than air, pockets of flammable gases also may develop. An effective monitoring program checks concentrations at multiple locations and times during the exposure period.

7.3.3 Exposure to Toxic Chemicals and Agents

Depending on the application of the ESP, collected dust may contain toxic chemicals or harmful physical agents. These compounds may exist in the system or be created as a result of operations in the confined area. Inhalation, ingestion, or skin contact can have adverse health effects. Most agents have threshold limit doses below which harmful effects do not occur; exposure above these threshold doses can cause acute or chronic symptoms, depending on the compound. A quantitative assessment of each compound and the threshold dose levels must be made before anyone enters the ESP. Typical toxic chemicals or species in the ESP environment include CO, H_2S, Total Reduced Sulfur (TRS) gases, arsenic, cadmium, beryllium, lead, alkali, and acids. If repair work is being conducted, organic solvents, zinc, or cadmium also may be present. Table 7-1 lists the allowable concentrations of several compounds in confined spaces for entry to be permissible.

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TABLE 7-1. EFFECTS OF VARIOUS LEVELS OF OXYGEN ON PERSONS[a]

Concentration, percent	Duration	Effect[b]
20.9	Indefinite	Usual oxygen content of air
19.5	Not stated	Minimum oxygen content for oxygen-deficient atmospheres (OSHA Standards)
16.5	Not stated	Lowest limit of acceptable standards reported in literature for entry without air-supplied respirators
12-16	Seconds to minutes	Increased pulse and respiration, some coordination loss
10-14	Seconds to minutes	Disturbed respiration, fatigue, emotional upset
6-10	Seconds	Nausea, vomiting, inability to move freely, loss of consciousness
Below 6	Seconds	Convulsions, gasping respiration followed by cessation of breathing and cardiac standstill.

[a] Data from correspondence of Robert A. Scala, Ph.D., REHD, Exxon Corporation, March 26, 1974.

[b] Effects - Only trained individuals know the warning signals of a low oxygen supply. The average person fails to recognize the danger until he is too weak to rescue himself. Signs include an increased rate of respiration and circulation that accelerates the onset of more profound effects, such as loss of consciousness, irregular heart action, and muscular twitching. Unconsciousness and death can be sudden.

As noted in Table 7-2, entry may be permitted within certain limitations provided the person is equipped with appropriate approved respiratory protection. An assessment of the hazard, concentration, permissible exposure, and protective equipment must be made before anyone is allowed to enter the equipment.

TABLE 7-2. ALLOWABLE CONCENTRATIONS FOR ENTRY INTO CONFINED SPACES

Agent[a]	Without breathing-air equipment	With air-supply breathing equipment	No entry permitted[b]
Hydrocarbons	1% LEL max.	20% LEL max.	Above 20% LEL
Oxygen	19.5-23.5%	16.5% min.	Below 16.5%
H_2S	10 ppm max.	300 ppm	>20 ppm
Carbon monoxide	30 ppm max.	200 ppm	>200 ppm
SO_2	5 ppm max.	500 ppm	>10 ppm

[a] If other contaminants are present, the industrial hygienist or REHD should be consulted for the appropriate allowable limits.

[b] Work may be performed in oxygen-free atmospheres if backup systems are available, such as air-line respirators, self-contained breathing apparatus, and an emergency oxygen escape pack.

Each facility must establish a confined-space entry policy that includes recognition of the hazards, atmospheric testing and analysis, ventilation requirements, selection and use of protective equipment, training and education of personnel, and administrative procedures.

An important component of the policy is recognition of the potential hazard, which requires complete knowledge of the industrial process and wash area. A cursory examination cannot prevent serious deficiencies; a detailed analysis is recommended.

The second policy component involves ambient air monitoring. An initial certification of gaseous concentrations must be made before entry is permitted. This certification must be made by a qualified safety officer with properly calibrated and maintained equipment. In general, a permit to enter (with a time limit) may be issued and displayed at the point of entry. Assuming that oxygen and gas levels do not change with time can be dangerous; an effective program should include periodic reevaluations of concentrations after initial entry.

Hazard Recognition--

Each worker should be trained in the use of protective equipment, potential hazards, early warning signs of exposure (symptoms), and rescue procedures (first aid, CPR, etc.). It is most important that each person be aware that multiple fatalities can occur if proper rescue procedures are not followed. If a worker is affected within the confined area and cannot remove himself, rescue personnel must not enter the area without complete self-contained breathing equipment. If the first worker is affected by an unknown agent, it is highly probable that rescue personnel will be similarly affected unless they have the proper protective equipment. Because the causal agent is not known, maximum protection must be used during the rescue attempt.

Atmospheric Testing and Analysis--

Gas monitoring usually is conducted to determine percent oxygen, percent lower explosive limit (hexane/methane, heptane, etc.), and hydrocarbon concentration (in parts per million), and carbon monoxide levels (in parts per million). If hydrogen sulfide or other toxic gases are suspected, additional analyses may be conducted with detection tubes or continuous gas samplers. The use of continuous gas samplers with an audible alarm is recommended. The initial measurements should be performed according to the following suggested procedures:

1. The ESP to be entered should be emptied, purged, cleaned, and ventilated to the maximum extent possible. All entry ports should be opened to facilitate mixing. All electrical and mechanical equipment must be locked out and posted. The confined space must be completely isolated by closing dampers, using guillotine dampers, or installing blanks.

2. A gas tester should check the vessel's oxygen content, explosivity, and toxic chemical concentration by first sampling all entry ports and then sampling inside the space with probes (while he remains outside). Caution should be used when testing for combustible gases, as many meters need an oxygen level close to ambient levels to operate correctly. This is one reason that the space should be purged and vented before testing. Voids, sub-enclosures, and other areas where pockets of gas could collect should also be tested.

3. When initial gas test results show that the space has sufficient oxygen, the gas tester can enter the space and complete the initial testing by examining areas inaccessible from outside the shell. He/she should wear an air-supplied positive-pressure respirator during these measurements. Special care should be taken to test all breathing zone areas.

4. If the results of the initial tests show that a flammable atmosphere still exists, additional purging and ventilation are required to

lower the concentration to 10 percent of the LEL before entry may be permitted.

5. If testing shows an oxygen-deficient atmosphere or toxic concentrations, all personnel entering the space must use an appropriate air-supplied respirator.

After the initial gas testing has been performed, dust, mists, fumes, and any other chemical agents present should be evaluated by either an industrial hygienist or a trained technician. The results will indicate if additional control measures are necessary. Physical agents such as noise, heat, and radiation must also be evaluated, and if any are present, the appropriate control measures (e.g., providing ear protection or rotating employees) should be instigated.

The specified respiratory protection should be based on the hazard assessment, i.e., the type of contaminant, its concentration, and the exposure time. The type of respiratory equipment required for each species is specified by NIOSH.

Respirators include basic particle-removing devices (dust, aerosol, mist, etc.), air-purifying respirators (gas, vapors, etc.), and air-supplying respirators (air-line, self-contained).

7.4 WORKER PROTECTION

Dust collected by ESP's is very fine and usually contains a high percentage of particles with diameters of less than 5 μm. The dust also may be sharp-edged or crystalline in nature. All surfaces in the ESP are coated with dust, and this material can be easily dislodged and suspended during internal inspections. Thermal drafts and/or cooling fans cause constant motion of dust particles in the gas stream.

7.4.1 Eye Protection

Eye protection is necessary to prevent dust from entering the eyes. Goggle-type protection is generally not effective because of the inability of the frames to form a tight seal against the worker's face. Effective eye protection consists of full-face protection, a snorkling mask, or eye goggles.

Eyes also may be subject to chemical damage as a result of the dust composition or species condensed onto the dust particles. The most common active agents are sulfuric acid on fly ash particles and alkali agents in ESP applications at cement facilities. Each plant should collect samples of ESP dust and specify eyewash solutions suitable for removing or neutralizing the active components. Table 7-3 summarizes the kinds of applications where potential eye hazards may exist.

TABLE 7-3. APPLICATIONS PRESENTING POTENTIAL EYE HAZARDS

Application	Potential active species	pH
Fly ash	Sulfuric acid	Acid
Cement	Alkali (NaOH, Na_2SO_4, K_2SC_4, etc.)	Alkaline
Kraft recovery	Sodium sulfate Sulfuric acid	Alkaline
Municipal incineration	Hydrochloric acid	Acid
Copper converter	Sulfuric acid	Acid

7.4.2 Hearing Protection

The ESP shell surrounds a large open area, and the metal walls that tend to reflect and amplify sound energy. When inspectors are inside the unit, they should use proper hearing protection to limit sound levels to maximum permitted exposure. Many types of hearing protection devices (cotton, premolded inserts, foam, ear muffs, etc.) are available; selection depends on individual preference and expected sound levels.

The major sources of sound energy are sonic horns and rappers. Because of their dangerous level of energy and sound pressure, sonic horns should be tied into the key-interlock system to prevent their activation while persons are inside the unit.

Activation of either internal failing hammer rappers or external rappers may become necessary during an inspection and evaluation of an ESP unit. The impact of these rappers results in high short-term sound levels and dislodges dust from plates.

Limits of worker exposure to noise are based on both durations of exposures and sound levels (dBA). Permissible levels for intermittent noise and nonimpulsive levels are presented in Tables 7-4 and 7-5.

TABLE 7-4. MAXIMUM PERMISSIBLE SOUND LEVELS FOR INTERMITTENT NOISE
(A weighted sound level, dBA)

Total time/8 hours	Number of occurrences per day						
	1	3	7	15	35	75	≥ 160
8 hours	89	89	89	89	89	89	89
6 hours	90	92	95	97	97	94	93
4 hours	91	94	98	101	103	101	99
2 hours	93	98	102	105	108	113	117
1 hour	96	102	106	109	114	125	125
½ hour	100	105	109	114	125		
¼ hour	104	109	115	124			
8 minutes	108	114	125				
4 minutes	113	125					
2 minutes	123						

TABLE 7-5. ACGIH THRESHOLD LIMIT VALUES FOR NONIMPULSIVE NOISE

Duration, hours/day	Permissible sound level, dBA
8.00	90
6.00	92
4.00	95
3.00	97
2.00	100
1.50	102
1.00	105
0.75	107
0.50	110
0.25	115

7.4.3 Skin Irritation

Depending on its composition, the dust collected in the ESP can be acidic, alkaline, hygroscopic, or abrasive. Skin contact with this dust can result in burns or irritation. Workers can limit skin contact area and thus prevent potential irritation by wearing long-sleeved shirts and gloves during internal inspections. Depending on temperature conditions and activity levels, coveralls or other full covering may be used.

7.4.4 Thermal Stress

Thermal stress associated with inspections and maintenance of an ESP and its components must be considered in defining the time required for repairs. Because of the dusty, humid conditions and limited access, thermal effects may be severe. Also if the time available for purging and cooling is limited, entry may have to be made under elevated temperatures.

The thermal stress placed on the worker is a function of several variables, such as air velocity, evaporation rate, humidity, temperature, radiation, and metabolic rate (work). In effect, the stress is indicated by the need to evaporate perspiration.

A Heat Stress Index developed by Belding and Hatch in 1955 incorporates environmental heat [radiation (R), convection (C), and metabolic (M)] into an expression of stress in terms of requirement for evaporation of perspiration. Algebraically the function may be stated as follows:

$$M \pm R \pm C = E\ \text{req.}$$

The resulting physiological strain is determined by the ratio of stress (E req.) to the maximum capacity of the environment (E max.). The resulting value is defined as the Heat Stress Index (HSI), which is calculated as:

$$\text{HSI} = \frac{E\ \text{req.}}{E\ \text{max.}} \times 100$$

The values for E req. and E max. are calculated at the maximum exposure time, based on the HSI defined. Generally, HSI maximum acceptable values are established for an 8-hour work day.

Table 7-6 indicates expected physiological and hygienic implications of an 8-hour exposure at various heat-stress levels.

TABLE 7-6. EXPLANATION OF VALUES IN BELDING AND HATCH HSI[a]

Index of Heat Stress (HSI)	Physiological and hygienic implications of 8-hour exposures to various heat stresses
-20 -10	Mild cold strain. This condition frequently exists in areas where men recover from exposure to heat.
0	No thermal strain.
+10 20 30	Mild to moderate heat strain. When a job involves higher intellectual functions, dexterity, or alertness, subtle to substantial decrements in performance may be expected. In performance of heavy physical work, little decrement expected unless ability of individuals to perform such work under no thermal stress is marginal.
40 50 60	Severe heat strain, involving a threat to health unless persons are physically fit. A break-in period required for those not previously acclimatized. Some decrement in performance of physical work is to be expected. Medical selection of personnel desirable because these conditions are unsuitable for anyone with cardiovascular or respiratory impairment or with chronic dermatitis. These working conditions are also unsuitable for activities requiring sustained mental effort.
70 80 90	Very severe heat strain. Only a small percentage of the population can be expected to qualify for this work. Personnel should be selected by medical examination and by trial on the job (after acclimatization). Special measures are needed to assure adequate water and salt intake. Amelioration of working conditions by any feasible means is highly desirable, and may be expected to decrease the health hazard and simultaneously increase efficiency. Slight "indisposition" that in most jobs would be insufficient to affect performance may render workers unfit for this exposure.
100	The maximum strain tolerated daily by fit, acclimatized, young men.

[a] Adapted from Belding and Hatch, "Index for Evaluating Heat Stress in Terms of Resulting Physiologic Strains," Heating, Piping and Air Conditioning, 1955.

A nomograph may be used to evaluate acceptable exposure times under various conditions. Figure 7-4 shows the methodology for calculating exposure time. Constants and variables used in the nomograph are as follows:

$$R = 17.5\ (Tw - 95)$$

$$C = 0.756\ V^{0.6}\ (Ta - 95)$$

$$E\ max. = 2.8\ V^{0.6}\ (42 - PWa)$$

where R = radiant heat exchange, Btu/h
C = convective heat exchange, Btu/h
E max. = maximum evaporative heat loss, Btu/h
Tw = mean radiant temperature, °F
Ta = air temperature, °F
V = air velocity, ft/min
PWa = vapor pressure, mm Hg
Twb = wet bulb temperature, °F
M = metabolic rate, Btu/h
Tg = globe temperature, °F

The example presented here illustrates the use of the nomograph under the following conditions: Tg = 130°F, Ta = 100°F, Twb = 80°F, V = 50 ft/min, M = 2000 Btu/h, and dew point = 73°F.

Step 1. Determine convection. Connect velocity (column I) with air temperature (Ta) column II and read on column III.

Step 2. Determine E max. Connect velocity (column I) and dew point column IV and read E max. on column V.

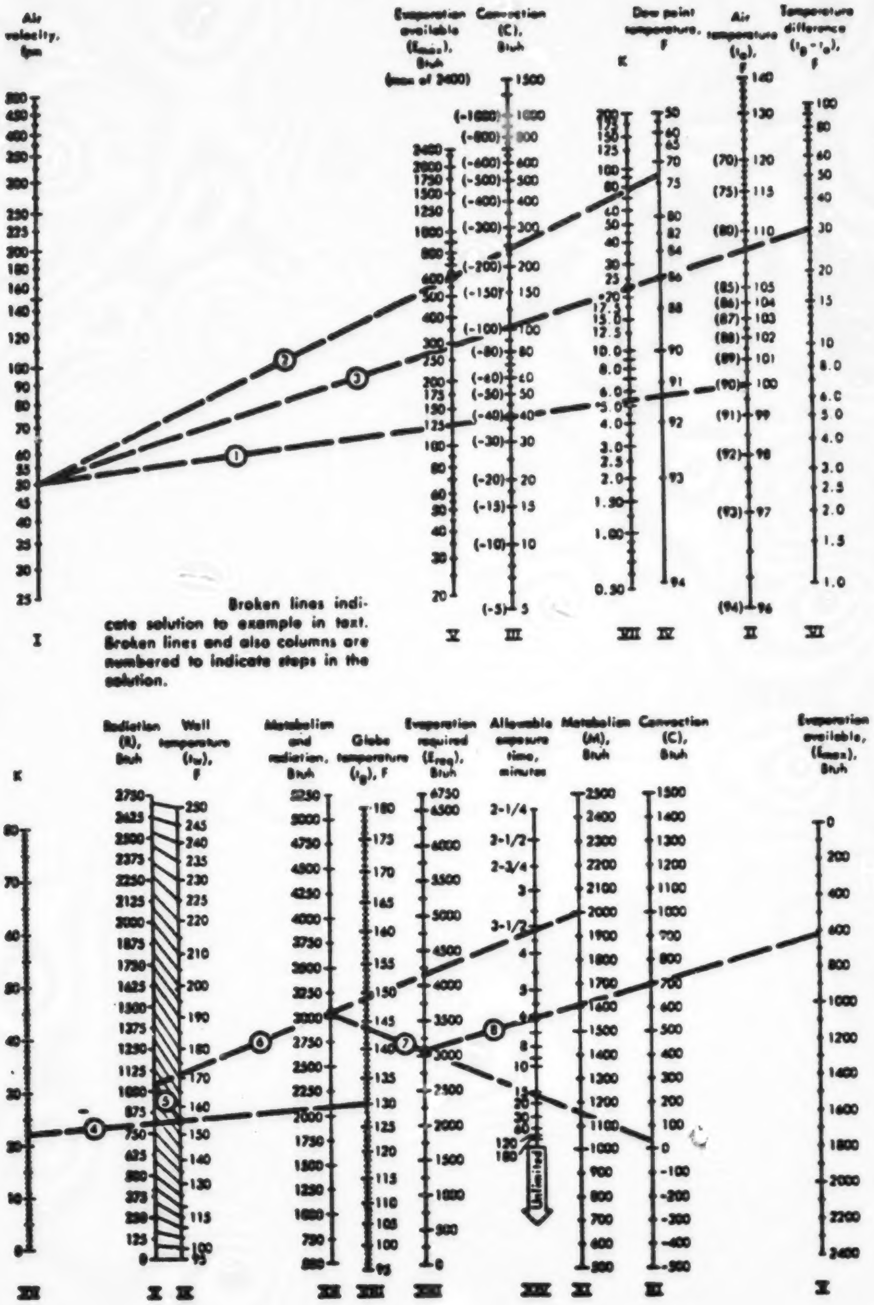
Step 3. Determine constant K. Connect velocity (column I) with Tg-Ta (column VI) and read K on column VII.

Step 4. Determine Tw. Connect K (column VII) and Tg (column VIII) and read Tw on column IX.

Step 5. Extend line in Step 4 to column X and read R.

Step 6. Connect R column X with M (column XI) read R + M on column XII.

Step 7. Connect C (column III) with R + M (column XII) and read E req. on column XIII.



Broken lines indicate solution to example in text. Broken lines and also columns are numbered to indicate steps in the solution.

Figure 7-4. Nomograph developed by McKarns and Brief incorporating the revised Fort Knox coefficients.

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Step 8. Connect E max. (column V) with E req. column XIII and read allowable exposure time on XIV.

Metabolic rate varies with exertion and work expended, and an estimate of M must be made for each effort expended in the ESP inspection or repair. Examples of M for several levels of activity are provided in Tables 7-7 and 7-8.

When the work involves lifting, pushing, or carrying loads; cranking; etc., the heat equivalent of the external work (W) is subtracted from the total energy output to obtain heat produced in the body (M).

TABLE 7-7. HEAT PRODUCTION FOR VARIOUS LEVELS OF EXERTION

Activity	cal/m²h
Sleeping	40
Sitting quietly	50
Working at a desk, driving a car, standing, minimum movement	80
Sentry duty, standing at machine and doing light work	100
Walking 2.5 mph on level, moderate work	150
Walking 3.5 mph on level, moderately hard work	200
Walking 3.5 mph on level with 45-lb load, hard work	300

TABLE 7-8. METABOLIC BODY HEAT PRODUCTION AS A FUNCTION OF ACTIVITY

Activity	kcal/h
At rest (seated)	90
Light machine work	200
Walking, 3.5 mph on level	300
Forging	390
Shoveling	450-600
Slag removal	700

SECTION 8
MODEL O&M PLAN

Generally, one or more individuals at a plant site have the responsibility of ensuring that an ESP is operated and maintained so that it meets design particulate matter removal efficiencies and the plant complies with regulatory emission limits.

Unfortunately, most O&M personnel do not receive in-depth training on the theory of ESP operation, diagnostic analysis, and the problems and malfunctions that may occur over the life of the unit. Plant personnel tend to learn about the operation of the specific unit and to gain operating experience as a result of day-to-day operating problems. This so-called "on-the-job" training can result in early deterioration or catastrophic failures that could have been avoided.

The purpose of this section is to present the basic elements of an O&M program that will prevent premature ESP failure. This program is not all-inclusive, and it does not address all potential failure mechanisms. Nevertheless, it ensures the user adequate knowledge to establish a plan of action, maintain a reasonable spare parts inventory, and keep the necessary records for analysis and correction of deficiencies in ESP operation.

The overall goal of an O&M plan is to prevent unit failures. If failures do occur, however, the plan must include adequate procedures to limit the extent and duration of excess emissions, to limit damage to the equipment, and to effect changes in the operation of the unit to prevent recurrence of the failure. The ideal O&M program includes requirements for recordkeeping, diagnostic analysis, trend analysis, process analysis, and an external and internal inspection program.

The components of an O&M plan are management, personnel, preventive maintenance, inspection program, specific maintenance procedures, and internal plant audits. The most important of these are management and personnel.

Without a properly trained and motivated staff and the full support of plant management, no O&M program can be effective.

8.1 MANAGEMENT AND STAFF

Personnel operating and servicing the ESP must be familiar with the components of the unit, the theory of operation, limitations of the device, and proper procedures for repair and preventive maintenance.

For optimum performance, one person (i.e., a coordinator) should be responsible for ESP O&M. All requests for repair and/or investigation of abnormal operation go through this individual for coordination of efforts. When repairs are completed, final reports also should be transmitted to the originating staff through the ESP coordinator. Thus, the coordinator will be aware of all maintenance that has been performed, chronic or acute operating problems, and any work that is in progress.

The coordinator, in consultation with the operation (process) personnel and management, also can arrange for and schedule all required maintenance. He/she can assign priority to repairs and order the necessary repair components, which sometimes can be received and checked out prior to installation. Such coordination does not eliminate the need for specialists (electricians, pipe fitters, welders, etc.) but it does avoid duplication of effort and helps to ensure an efficient operation.

Many ESP failures and operating problems are caused by mechanical deficiencies. These are indicated by changes in electrical power readings. By evaluating process conditions, electrical readings, inspection reports, and the physical condition of the unit, the coordinator can evaluate the overall condition of the unit and recommend process modifications and/or repairs.

The number of support staff required for proper operation and maintenance of a unit is a function of unit size, design, and operating history. Staff requirements must be assessed periodically to ensure that the right personnel are available for normal levels of maintenance. Additional staff will generally be needed for such activities as a major rebuilding of the unit and/or structural changes. This additional staff may include plant personnel, outside hourly laborers, or contracted personnel from service companies or ESP vendors. In all cases, outside personnel should be supervised by experienced plant personnel. The services of laboratory personnel and computer analysts may also be needed. The coordinator should be responsible for final acceptance and approval of all repairs. Figure 8-1 presents the general concept and staff organizational chart for a centrally coordinated O&M program.

As with any highly technical process, the O&M staff responsible for the ESP must have adequate knowledge to operate and repair the equipment.

Many components of an ESP are not unique, and special knowledge is not required regarding the components themselves; however, the arrangement and installation of these components are unique in most applications, and special knowledge and care is necessary to achieve their optimum performance.

Many plants have a high rate of personnel turnover, and new employees are assigned to work on an ESP who may have had no previous contact with air pollution control equipment. To provide the necessary technical expertise, the source must establish a formal training program for each employee assigned to ESP maintenance and operation.

An optimum training program should include the operators, supervisors, and maintenance staff. Many electric utilities, kraft pulp mills, and cement plants indicated that more than 70 percent of the ESP problems are non-ESP related. Changes in operation that affect resistivity, particle size, temperature, and the carbon content of ash entering the unit have a detrimental effect on removal efficiency. The process operator has control over many of these variables. An understanding of the cause-and-effect relationship between process conditions and ESP can help to avoid many performance problems. Safety is an important aspect of any training program. Each person associated with the unit should have complete instructions regarding electrical hazards, confined area entry, first aid, and lock-out/tag-out procedures.

Thus, a typical ESP training program should include safety, theory of operation, a physical description of the unit, a review of subsystems, normal operation (indicators), and abnormal operations (common failure mechanisms), troubleshooting procedures, a preventive maintenance program, and recordkeeping.

The O&M program should emphasize optimum and continuous performance of the unit. The staff should never get the impression that less-than-optimum

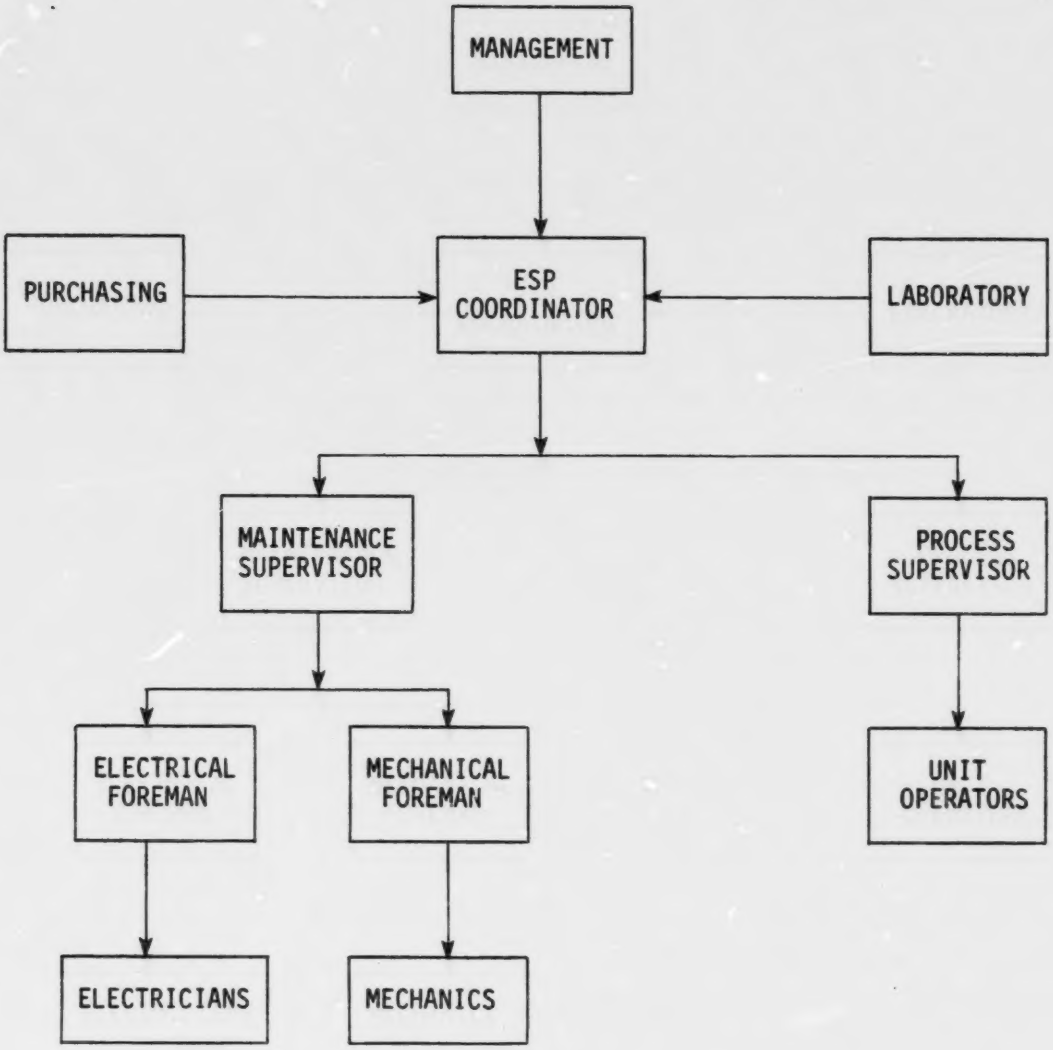

Figure 8-1. Organizational chart for centrally coordinated ESP O&M program.

ESP performance is acceptable. Redundancy is established in the unit solely to provide a margin of safety for achieving compliance during emergency situations. Once a pattern is established that allows a less-than-optimum condition to exist (i.e., reliance on built-in redundancy), less-than-optimum performance becomes the norm, and the margin of safety begins to erode.

To reenforce the training program, followup written material should be prepared. Each plant should prepare and continually update an ESP operating manual and an ESP maintenance manual for each unit. A generic manual usually is not adequate because each vendor's design philosophy varies. The use of actual photographs, slides, and drawings aid in the overall understanding of the unit and reduce lost time during repair work.

Training material and courses available from manufacturers and vendors should be reviewed and presented as appropriate. Further, staff members responsible for each unit should attend workshops, seminars, and training courses presented by the Electric Power Research Institute (EPRI), the Association of Pulp and Paper Industries (TAPPI), the Portland Cement Association (PCA), EPA, and other organizations to increase the scope of the knowledge and to keep current with evolving technology.

8.2 MAINTENANCE MANUALS

Specific maintenance manuals should be developed for each ESP at a source. The basic elements of design and overall operation should be specific to each ESP and should incorporate the manufacturer's literature and in-house experience with the particular type of unit. The manual should relate to the physical aspects of the unit. Descriptions should be brief and to the point; long narratives without direct application should be avoided.

Figure 8-2 presents a suggested outline for a typical manual. The manual should begin with such basic concepts as ESP description and operation. It can then continue with a section on component parts which should include detailed drawings and an explanation of the function of each component and its normal condition.

The next section covers the internal inspection and maintenance procedure, which is extremely critical in maintaining performance. Periodic

- A. PRECIPITATOR DESCRIPTION (GENERAL)
  - 1. Collection Zone
  - 2. Power Supply
  - 3. Ash Removal System
- B. DESCRIPTION OF OPERATION
  - 1. Ionization Concepts
  - 2. Ash Removal (Plates and Wires)
- C. SAFETY
  - 1. Interlock System
  - 2. Tagging Procedure
  - 3. Grounding Rods
- D. COMPONENT DESCRIPTION
  - 1. Collection Plate System
  - 2. Emitter Wire System
  - 3. Power Supply (T-R Set)
  - 4. Linear Reactor
  - 5. Control Cabinet (AVC)
  - 6. Plate Rapper System
  - 7. Wire Rapper System
- E. INTERNAL INSPECTION AND MAINTENANCE
  - 1. Electrode Alignment
    - a. Plate to Wire Clearance
    - b. Bowed Plates
    - c. Loose Plate Clips
  - 2. Inlet and Outlet Ducts
    - a. Ash Build-up
    - b. Gas Distribution Devices
  - 3. Hoppers
    - a. Ash Build-up in Hoppers
    - b. Hopper Heater Operation
  - 4. All Areas
    - a. Corrosion
- F. EXTERNAL INSPECTION AND MAINTENANCE
  - 1. T-R Sets
    - a. Oil Leakage
    - b. Oil Sample
    - c. Loose Connections
  - 2. Control Cabinet
    - a. Cleanliness
    - b. Loose Connections
    - c. Air Filter
  - 3. Linear Reactor
    - a. Loose Connections
  - 4. Insulators (Support, Antisway, Bus Duct, T-R Bushings)
    - a. Cleanliness
    - b. Cracks
    - c. Tracking
  - 5. Plate Rappers and Wire Vibrators
    - a. Check Operation
  - 6. Air Leakage
    - a. Expansion Joints
    - b. Door Gaskets
    - c. Rapper Rod Penetrations
    - d. Hoppers
  - 7. Interlocks
    - a. Check Operation
    - b. Lubricate
- G. REENERGIZING ESP AFTER MAINTENANCE
  - 1. Air Load

APPENDIX

- 1. Inspection and Maintenance Checklist
- 2. ESP Layout Details

Figure 8-2. Outline for ESP Maintenance Manual.[1]

checks are necessary to maintain alignment, to remove accumulated ash deposits, and to prevent air inleakage. The section on external inspection and maintenance includes all supporting equipment, such as T-R sets, control cabinets, linear reactors, insulators, rappers, etc. Each of these sections should provide a procedure for evaluating the component. The manual should identify key operating parameters, define normal operation, and identify indicators of possible deviations from normal condition. Key operating parameters include temperature, air pressure, voltage drops, current levels, or other parameters that can be used to establish the basic operating condition of the unit.

After evaluation of conditions, a procedure must be presented to replace, repair, or isolate each component. Unless a proper procedure is followed, the corrective action could result in further damage to the unit, excessive emissions, or repeated failure.

8.3 OPERATING MANUALS

Whereas maintenance manuals are designed to facilitate physical repairs to the ESP, operating manuals are needed to establish an operating norm or baseline for each unit. Maintenance of the physical structure cannot ensure adequate performance of the unit because gas stream conditions such as temperature, SO_3 content, moisture, and gas volume affect the charging and collection mechanisms.

The operating manual should parallel the maintenance manual in terms of introductory material so that the operators and maintenance personnel have the same basic understanding of the components and their function and of the overall operating theory. Additional information should be provided on the effects of major operating variables such as gas volume, gas temperature, and resistivity. The manual also should discuss the effects of air inleakage on power levels (sparking) and the points where inleakage may occur (hoppers, doors, expansion points, etc.). Figure 8-3 presents an outline for an operating manual.

With regard to fuel combustion sources, the manual should discuss the effects of such process variables as burner conditions, burner alignment, and pulverizer fineness, which change the ash particle composition and size

A. DESCRIPTION OF PRECIPITATOR INDICATIONS
- 1. Power Supply
- 2. Collection Zone
- 3. Material Removal Apparatus

B. DESCRIPTION OF OPERATION
- 1. Ionization Concepts
- 2. Material Removal (Plates and Wires)

C. OPERATIONAL FACTORS
- 1. Gas Volume
  - a. Excess Air
  - b. Air Inleakage
    - (1) Hoppers
    - (2) Access Doors
    - (3) Expansion Joints
    - (4) Test Ports
    - (5) Air Heater Leakage
    - (6) Boiler Inspection Ports
- 2. Gas Temperature
  - a. High Temperature
  - b. Low Temperature
    - (1) Acid Dew Point
- 3. Carbon Carryover
  - a. Burner Conditions
  - b. Burner Alignment
  - c. Pulverizer Fineness
  - d. Oxygen
- 4. Rapper Malfunctions
  - a. Wire Rappers
  - b. Plate Rappers

D. ASH REMOVAL SYSTEM MALFUNCTION
- 1. Plugged Hopper
- 2. Low Vacuum
  - a. Excess Air Inleakage
  - b. Valves Stuck Open

E. METER READING
- 1. Normal or High Primary and Secondary Current - No Primary and Secondary Voltage
  - a. Wire Shorted to Ground
    - (1) Slack Wire
    - (2) Broken Wire
  - b. Full Hopper
    - (1) Vacuum system failed
    - (2) Bus section open
- 2. Normal or High Primary and Secondary Volts - No Primary and Secondary Current
  - a. Open Circuit
    - (1) T-R Failure
    - (2) Bus Section Open
- 3. Fluctuating Voltage and Current
  - a. Bus Section Swinging
    - (1) Antisway Insulator Broken

F. STARTUP
- 1. Safety Check
  - a. Personnel Clear
  - b. Ground Straps Removed
- 2. Ash Removal System On
- 3. ICVS System On
- 4. Power On To T-R's
- 5. Rappers On
- 6. Hopper Heaters On

G. SHUTDOWN
- 1. Power Down To T-R's
- 2. Precipitator Keyed Out
- 3. Rappers Turned Off 1 Hour After T-R's
- 4. If Long Outage, ICVS System, Hopper Heaters, and Ash Removal System Turned Off

Figure 8-3. ESP Operating Manual outline.[1]

distribution. An expected normal range of values and indicator points should be established as reference points for the operator.

Another important section of the manual is the one which deals with the cause-and-effect relationships between meter readings and performance. This diagnostic section can be generic, in that it provides basic information such as indications of grounds, swinging wires, etc.; however, it should also include data that are unique to a specific unit.

Startup and shutdown procedures should be established, and step-by-step instructions should be provided to ensure sequenced outage of equipment to aid in maintenance activities and to eliminate startup problems.

8.4 SPARE PARTS

An inventory of spare parts should be maintained to replace failed parts as needed. Because all components or subassemblies cannot be stocked, a rational system must be developed that establishes a reasonable inventory of spare parts. Decisions regarding which components to include in the spare parts inventory should be based on the following:

1. Probability of failure
2. Cost of components
3. Replacement time (installation)
4. Whether the part can be stored as a component or subassembly (i.e., rapper coil vs. rapper, rapper cam vs. cam shaft contacts)
5. In-house technical repair capabilities
6. Available space

The probability of failure can be developed from outside studies (e.g., EPRI), vendor recommendations, and a history of the unit. It is reasonable to assume that components subjected to heat, dust, weather, or wear are the most likely to fail. Components of this type are no different from those in process service, and reasonable judgment must be used in deciding what to stock. Mechanical and electrical maintenance staff members should be consulted for recommendations concerning some items that should be stocked and the number required. Adjustments can be made as operating experience is gained. Items that fall into this category include rappers, drive belts, switch contacts, rapper motor drives, rapper switch cams, rapper boots, complete insulator heaters, and level indicators.

If a unit is subjected to chronic hopper pluggage problems, antisway insulators may receive abnormal stress and thus be subject to potential failure. Also, if the unit is a cycling unit, the probability of insulator tracking and failure is increased and may warrant the stocking of support insulators.

Another factor in defining a spare parts inventory is the cost of individual components. Although stocking rappers or rapper components is not costly, stocking a spare transformer can be quite costly. Maintaining an extensive inventory of high-cost items that have low probability of failure is not justified.

The time required to receive the part from the vendor and the time required to replace the part on the unit also influence whether an item should be stocked. For example, an insulator could be obtained from the vendor in less than 24 hours. If the shutdown, cooldown, and purge period for the unit is 18 hours and 2 hours are required to remove the broken insulator, little time can be saved by stocking the insulator. On the other hand, if the lead time for a critical part is a matter of weeks or months, or if a component must be specially built, stocking such items is advantageous.

Many plants have a highly trained electronics and mechanical shop whose staff can repair or rebuild components to meet original design specifications. The availability of this service can greatly reduce the need to maintain component parts or subassemblies. In these cases, one replacement can be stocked for installation during the period when repairs are being made. For example, many printed circuit boards can be repaired internally, which reduces the need to stock a complete line of electronic spare parts.

8.5 WORK ORDER SYSTEMS

A work order system is a valuable tool that allows the ESP coordinator to track unit performance over a period of time. Work order and computer tracking systems are generally designed to ensure that the work has been completed and that charges for labor and parts are correctly assigned for accounting and planning purposes. With minor changes in the work order form

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and in the computer programs, the work order also can permit continuous updating of failure-frequency records and can indicate whether the maintenance performed has been effective in preventing repeated failures. In general, the work order serves three basic functions:

1. It authorizes and defines the work to be performed.
2. It verifies that maintenance has been performed.
3. It permits the direct impact of cost and parts data to be entered into a central computerized data handling system.

To perform these functions effectively, the work order form must be specific, and the data fields must be large enough to handle detailed requests and to provide specific responses. In many computerized systems, the data entry cannot accommodate a narrative request and specific details are lost.

Most systems can accommodate simple repair jobs because they do not involve multiple repairs, staff requirements, or parts delays. Major repairs, however, become lost in the system as major events because they are subdivided into smaller jobs that the system can handle. Because of this constraint, a large repair project with many components (e.g., a transformer failure, control panel repair, or insulator failure) that may have a common cause appears to be a number of unrelated events in the tracking system.

For diagnostic purposes, a subroutine in the work order system is necessary that links repairs, parts, and location of failure in an event-time profile. Further, the exact location of component failures must be clearly defined. In effect, it is more important to know the pattern of failure than the cost of the failure.

The goal of the work order system can be summarized in the following items:

- To provide systematic screening and authorization of requested work.
- To provide the necessary information for planning and coordination of future work.
- To provide cost information for future planning.
- To instruct management and craftsmen in the performance of repair work.

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- To estimate manpower, time, and materials for completing the repair.
- To define the equipment that may need to be replaced, repaired, or redesigned (work order request for analysis of performance of components, special study, or consultation, etc.).

Repairs to the unit may be superficial or cosmetic in nature or they may be of an urgent nature and require emergency response to prevent damage or failure. In a major facility, numerous work order requests may be submitted as a result of daily inspections or operator analysis. Completing the jobs in a reasonable time requires scheduling the staff and ordering and receiving parts in an organized manner.

For effective implementation of the work order system, the request must be assigned a level of priority as to completion time. These priority assignments must take into consideration plant and personnel safety, the potential effect on emissions, potential damage to the equipment, maintenance personnel availability, part availability, and boiler or process availability. Obviously, all jobs cannot be assigned the highest priority. Careful assignment of priority is the most critical part of the work order system and the assignment must be made as quickly as possible after requests are received. An example of a five-level priority system is provided in Figure 8-4.

If a work order request is too detailed, it will require extensive time to complete. Also, a very complex form leads to superficial entries and erroneous data. The form should concentrate on the key elements required to document the need for repair, the response to the need (e.g., repairs completed), parts used, and manpower expended. Although a multipage form is not recommended, such a form may be used for certain purposes. For example, the first page can be a narrative describing the nature of the problem or repair required and the response to the need. It is very important that the maintenance staff indicate the cause of the failure and possible changes that would prevent recurrence. It is not adequate to simply make a repair to malfunctioning rapper controls and respond that "the repairs have been made." Unless a detailed analysis is made of the reason for the failure, the event may be repeated several times. Treating the symptom (making the repair;

WORKORDER PRIORITY SYSTEM

Priority	Action
1	Emergency repair.
2	Urgent repair to be completed during the day.
3, 4	Work which may be delayed and completed in the future.
5	Work which may be delayed until a scheduled outage.

Figure 8-4. Example of five-level priority system

replacing parts, fuses; etc.) is not sufficient; the cause of the failure must be treated.

In summary, the following is a list of how the key areas of a work order request are addressed:[2]

1. Date - The date is the day the problem was identified or the job was assigned if it originated in the planning, environmental, or engineering sections.

2. Approved by - This indicates who authorized the work to be completed, that the request has been entered into the system, and that it has been assigned a priority and schedule for response. The maintenance supervisor or ESP coordinator may approve the request, depending on staff and the size of the facility. When emergency repairs are required, the work order may be completed after the fact, and approval is not required.

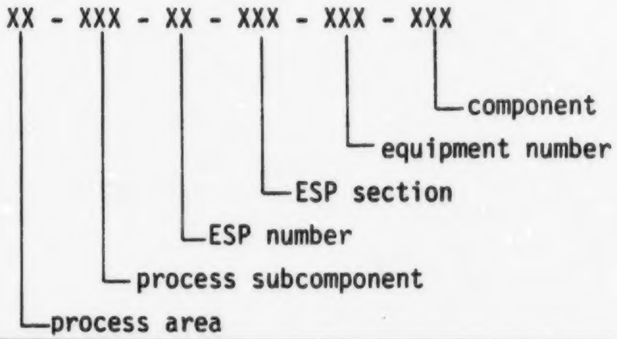
3. Priority - Priority is assigned according to job urgency on a scale of 1 to 5.

4. Work order number - The work order request number is the tracking control number necessary to retrieve the information from the computer data system.

5. Continuing or related work order numbers - If the job request is a continuation of previous requests or represents a continuing problem area, the related number should be entered.

6. Equipment number - All major equipment in an ESP should be assigned an identifying number that associates the repair with the equipment. The numbering system can include process area, major process component, ESP number, ESP section (i.e., chamber, field, inlet, outlet, etc.), equipment number, and component. This numeric identification can be established by using a field of grouped numbers. For example, the following could be used:

   ID number



If the facility only has one ESP and one process, the first five numbers (two groups) may not be required, and the entry is thus simplified. The purpose of the ID system is to enable analysis of the number of events and cost of repair in preselected areas of the ESP. The fineness or detail of the equipment ID definition will specify the detail available in later analyses.

7. Description of work - The request for repair is usually a narrative describing the nature of the failure, the part to be replaced, or the work to be completed. The description must be detailed but brief because the number of characters that can be entered into the computerized data system is limited. Additional pages of lengthy instruction regarding procedures may be attached to the request (not for computer entry).

8. Estimated labor - Assignment of personnel and scheduling of outages of certain equipment require the inclusion of an estimate of man-hours, the number of in-house staff needed, and whether outside labor is needed. The more complex jobs may be broken down into steps, with different personnel and crafts assigned for specific responsibilities. Manpower and procedures in the request should be consistent with procedures and policies established in the O&M manual.

9. Material requirements - In many jobs, maintenance crews will remove components before a detailed analysis of the needed materials can be completed; this can extend an outage while components or parts are ordered and received from vendors or retrieved from the spare parts inventory. Generally the cause of the failure should be identified at the time the work order request is filled, and specific materials needs should be identified before any removal effort begins. If the job supervisor knows in advance what materials are to be replaced, expended, or removed, efficiency is increased and outage time reduced. Also, if parts are not available, orders may be placed and received prior to the outage. Material requirements are not limited to parts; they also include tools, safety equipment, etc.

10. Action taken - This section of the request is the most important part of the computerized tracking system. A narrative description of the repair conducted should be provided in response to the work order request. The data must be accurate and clearly respond to the work order request.

11. Materials replaced - An itemized list of components replaced should be provided for tracking purposes. If the component has a preselected ID number (spare parts inventory number), this number should be included.

Actual manhours expended in the repair can be indicated by work order number on separate time cards and/or job control cards by craft and personnel number.

Copies of work orders for the ESP should be retained for future reference. The ESP coordinator should review these work orders routinely and make design changes or equipment changes as required to reduce failure or downtime. An equipment log also should be maintained, and the work should be summarized and dated to provide a history of maintenance to the unit.

Figure 8-5 shows a simplified work order request form. Changes in design for individual applications and equipment must be made to meet site-specific requirements.

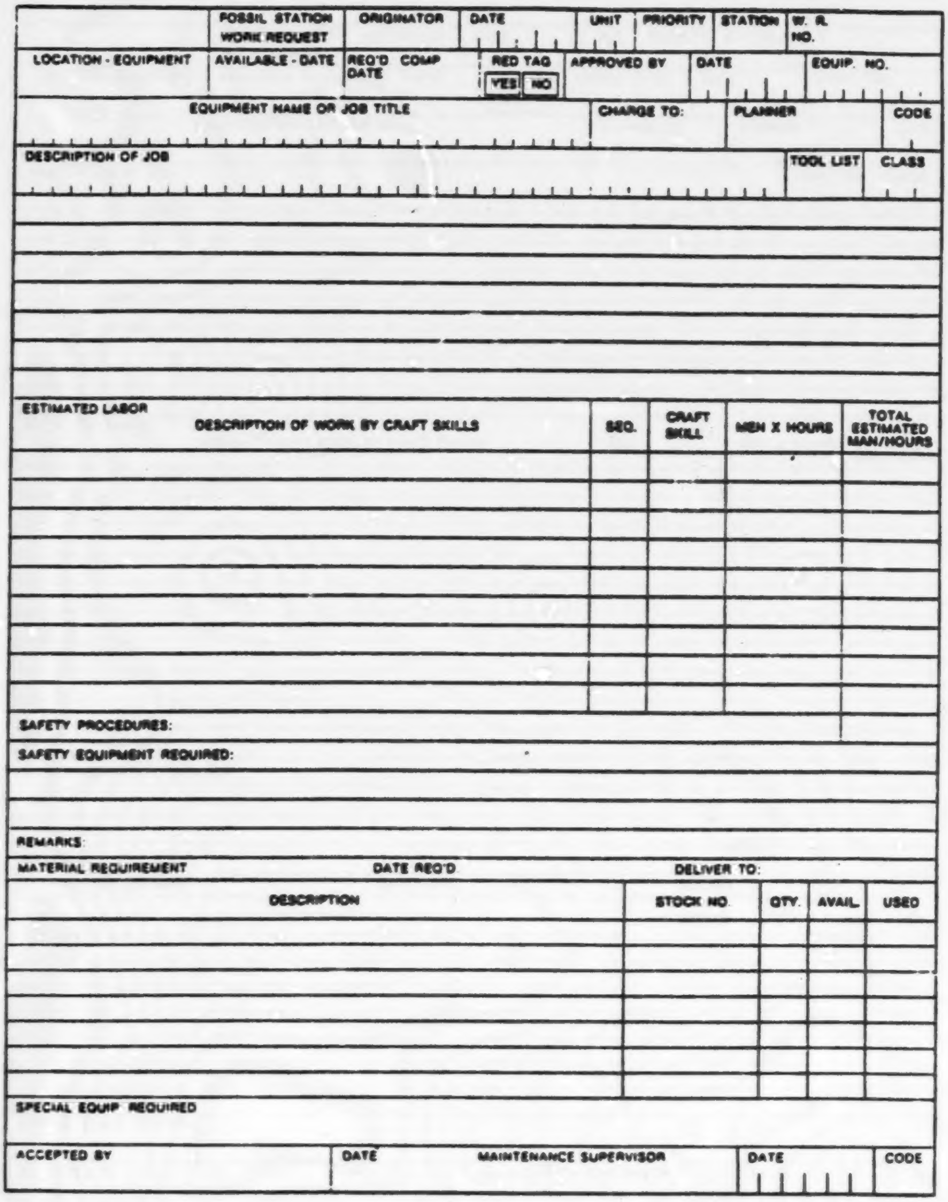
8.6 COMPUTERIZED TRACKING

8.6.1 Work Orders

If the work completed and parts used in the ESP have been entered in the computerized work order system with sufficient detail, maintenance and management personnel can evaluate the effectiveness of ESP maintenance.

Preventive maintenance (PM) manhours versus repair manhours also can be compared to evaluate the effectiveness of the current PM program. The level of detail may allow tracking of the impact of PM on particular subgroups (e.g., rappers, hoppers) as changes are made in PM procedures. The effectiveness of the PM program may be further evaluated by the required number of emergency repairs versus scheduled repairs over a period of time (i.e., priority 2 versus priority 5, etc.).

Although an evaluation of the frequency of component failures is an important benefit of computerized systems, improving ESP performance is the ultimate objective. The actual number of failures generally are not realized by the maintenance staff when several people are involved in performing maintenance. The temporal and spatial distribution of failures can provide insight into the cause of many failures. For example, if T-R set trips occur more frequently during wet, cold weather, the cause could be related to moisture in the conduit or a roof leak. If, however, T-R trips are associated



	FOSSIL STATION WORK REQUEST	ORIGINATOR	DATE	UNIT	PRIORITY	STATION	W. R. NO.
LOCATION - EQUIPMENT	AVAILABLE - DATE	REQ'D COMP DATE	RED TAG ☐ YES ☐ NO	APPROVED BY	DATE	EQUIP. NO.	

EQUIPMENT NAME OR JOB TITLE	CHARGE TO:	PLANNER	CODE
DESCRIPTION OF JOB	TOOL LIST	CLASS	

ESTIMATED LABOR

DESCRIPTION OF WORK BY CRAFT SKILLS	SEQ.	CRAFT SKILL	MEN X HOURS	TOTAL ESTIMATED MAN/HOURS

SAFETY PROCEDURES:

SAFETY EQUIPMENT REQUIRED:

REMARKS:

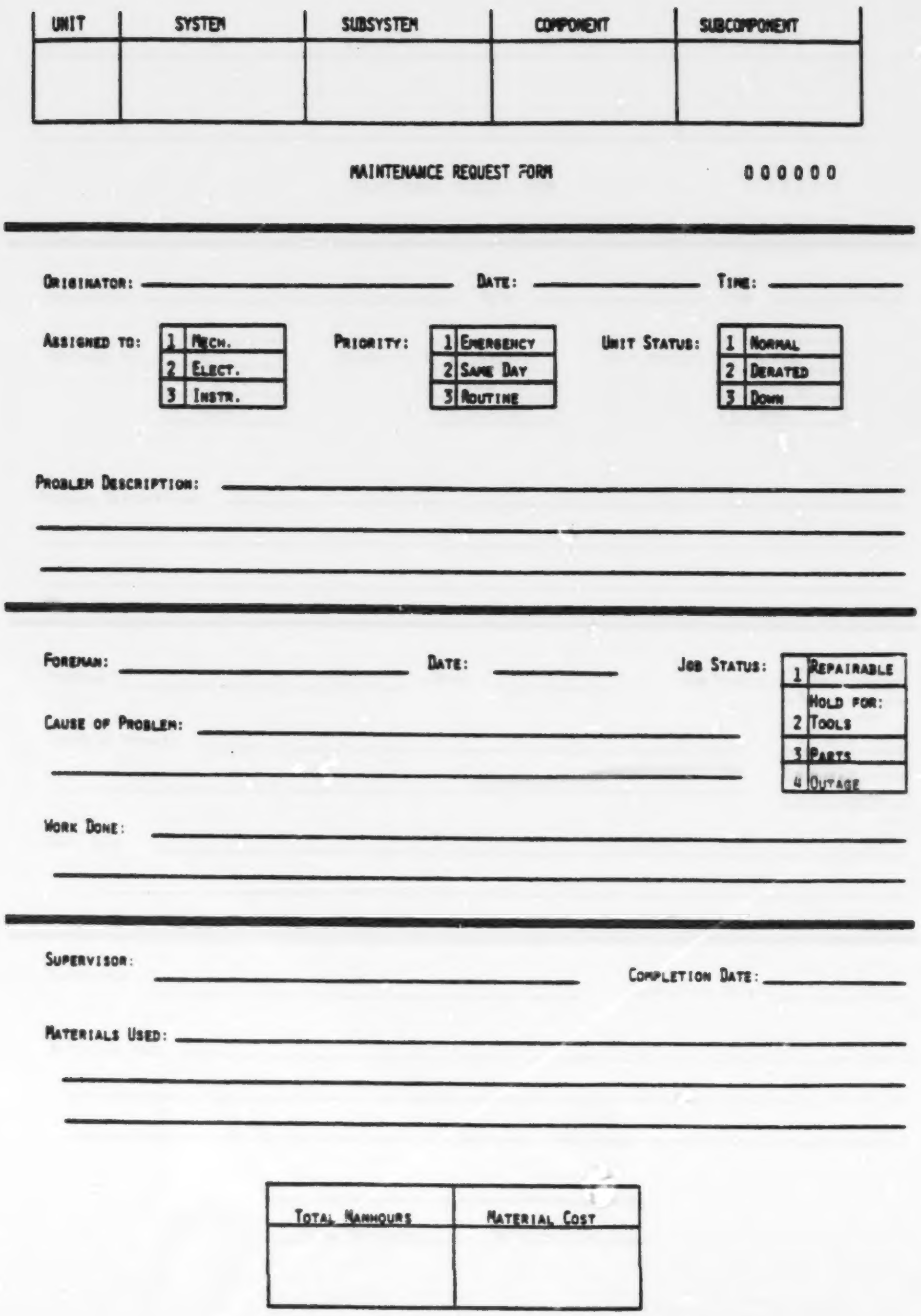
MATERIAL REQUIREMENT DATE REQ'D DELIVER TO:

DESCRIPTION	STOCK NO.	QTY.	AVAIL.	USED

SPECIAL EQUIP REQUIRED

ACCEPTED BY	DATE	MAINTENANCE SUPERVISOR	DATE	CODE

Figure 8-5a. Example of work order form.[2]



UNIT	SYSTEM	SUBSYSTEM	COMPONENT	SUBCOMPONENT

MAINTENANCE REQUEST FORM 000000

ORIGINATOR: ______ DATE: ______ TIME: ______

ASSIGNED TO: 1 MECH. 2 ELECT. 3 INSTR.

PRIORITY: 1 EMERGENCY 2 SAME DAY 3 ROUTINE

UNIT STATUS: 1 NORMAL 2 DERATED 3 DOWN

PROBLEM DESCRIPTION: ______

FOREMAN: ______ DATE: ______

JOB STATUS: 1 REPAIRABLE 2 HOLD FOR: TOOLS 3 PARTS 4 OUTAGE

CAUSE OF PROBLEM: ______

WORK DONE: ______

SUPERVISOR: ______ COMPLETION DATE: ______

MATERIALS USED: ______

TOTAL MANHOURS	MATERIAL COST

Figure 8-5b. Example of work order form.[3]

with hot, humid conditions, the electronic components may be overly sensitive to temperature. Cyclic events can be correlated with process operation or fuel changes that modify the ash characteristics.

It should be emphasized that the purpose of the computerized tracking system is not to satisfy the needs of the accountants or programmers, or to state that the plant has such a system. Rather, the purpose of a computerized tracking system is to provide the necessary information to analyze ESP maintenance practices and to reduce component failures, excess emissions, and outage time. The maintenance staff and ESP coordinator must clearly define the kind of data required, the level of detail, and the type of analysis required prior to the preparation of the data-handling and report-writing software. Examples of output may be man-hours by department, man-hours by equipment ID, number of repairs, number of events, number of parts, and frequency of events. Figures 8-6, 8-7, and 8-8 are examples of outputs from a computerized tracking system.

8.6.2 ESP Operating Parameters

In addition to tracking work orders, the computer can be used to develop correlations between process and ESP parameters and observed emission profiles. Depending on the type of cycles expected in process operation, the data may be continuously input into the system or it may be entered from operating logs or daily inspection reports once or twice a week.

The key data for tracking performance are ESP power levels (i.e., secondary meter reading by field), opacity (i.e., 6-minute averages), SO_2 levels, boiler load (or associated parameter proportional to gas flow volume), flue gas temperature, and fuel quality data (i.e., fuel source, sulfur, fineness, etc.).

The dampening effect of dust layers on plates, coal bunker hold-up time, and bunker rat hole problems may prohibit exact temporal correlations. In many cases, coal changes may have a final effect on power levels several hours after its introduction into the furnace. Combustion problems (i.e., residual carbon) will generally surface immediately because carbon is carried through the ESP by reentrainment.

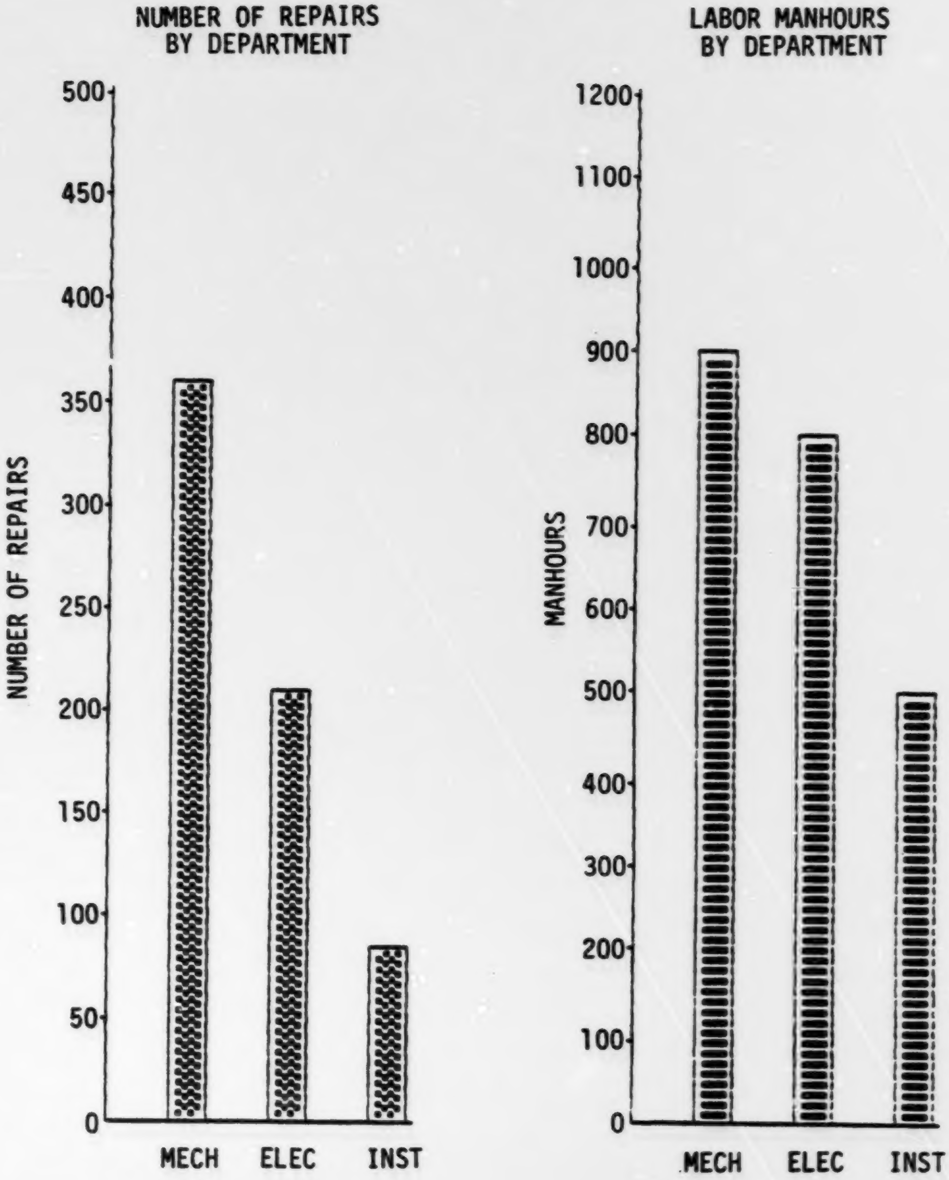


Figure 8-6. Example of Department Profile.[3]

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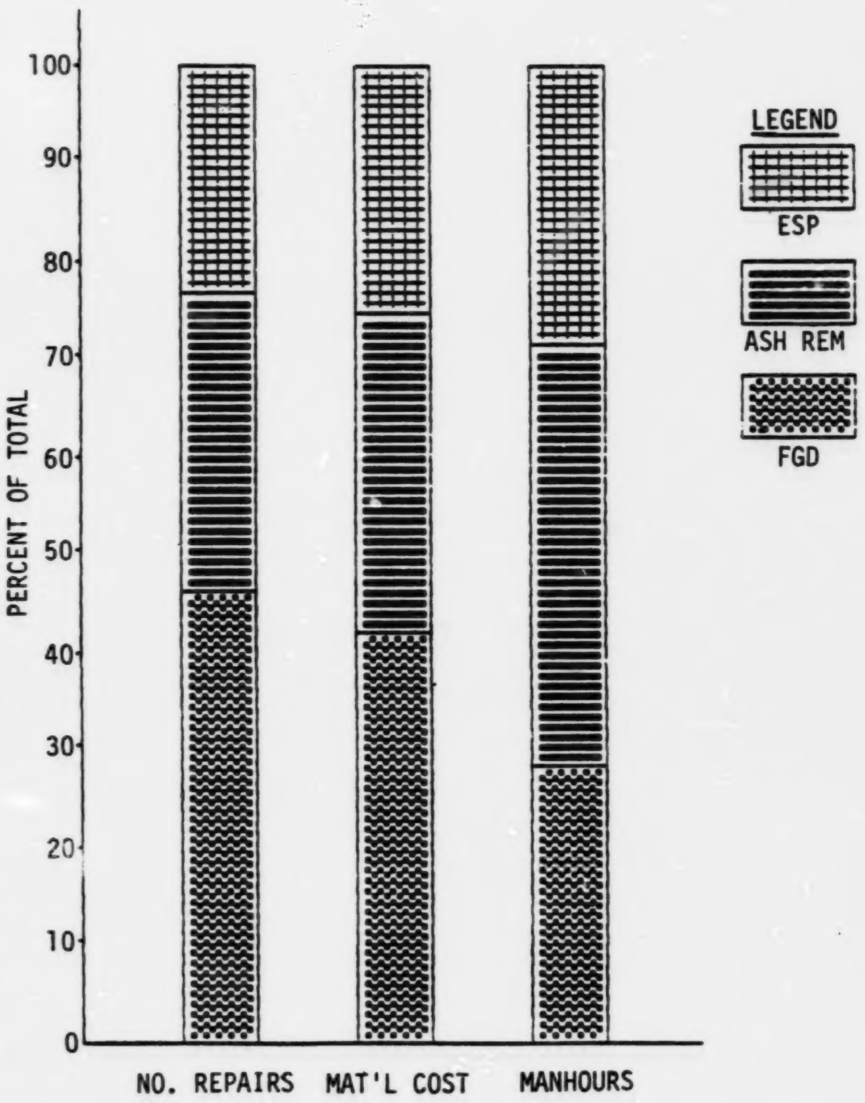

Figure 8-7. Example of Maintenance Summary.[3]

30d

```
  EQUIPMENT   DATE   UNIT   PRTY REQUEST JOB NAME                         DESCRIPTION
***
* 164451    04/10/81 002      3 11940   2AF-11                           CHECK AND REPAIR LEVEL CONTROLS
* 164451    08/27/81 002      3 53691   2AF-11                           2-AF-11
* 164451    09/06/81 002      3 23390   2AF-11                           UNSTOP VENT LINE
* 164451    09/07/81   2      3 53796   02-AF-11 HOPPER TOP GATE         2-AF-11 ASH HOPPER TOP GATE
* 164451    09/23/81  02      3 12710   2AF11                            ADJUST LEVEL CONTROL
* 164451    01/11/82  02      2 54455   2AF-11                           2-AF-11 BOT GATE
* 164451    02/14/82  02      3 55031   2AF 11                           2-AF-11 VENT VLV SOL
* 164452    11/10/80 002      2 51906   2AF-12                           2-AF-12 ASH HOPPER
* 164452    01/30/81 002      3 52447   2AF-12                           2AF-12 VENT VLV SOL
* 164453    01/27/81 002      3 52436   2AF-13                           2-AF-13 VENT VALVE
* 164453    01/10/82 002      2 23926   2BF-13                           REPLACE AIR CYLINDER
* 164453    01/11/82   2      2 54449   02 AF-13 HOPPER VENT VALVE       2-AF-13 VENT VALVE SOL
* 164453    01/17/82   2      3 54094   2AF 13                           2-AF-13 VENT VLV SOL.
* 164454    01/24/80   2      2 17000   2AF14                            2AF14 3WAY VLV
* 164454    09/01/81  02      4 53760   2AF-14                           2-AF-14 INSULATION
* 164454    02/03/82   2      3 13261   02-AF-14 HOPPER                  TIGHTEN BINDICATOR
* 164455    01/03/80   2      2 16901   2AF-15                           VENT LINE HAS A HOLE AT ELBOW WHERE
* 164455    01/10/80   2      2 16931   2BF-15                           REPLACE 2B-15 VENT IN SOLONOID
* 164455    01/15/81 002      4 52363   2AF-15 HOOPER                    2-AF-15-HOPPER
* 164455    02/22/81   2      2 11636   02 AF 15 NUVA FEEDER             CHECK OVERFILL ALARM
* 164455    02/24/81 002      3 11667   2AF-15                           CHECK HI ASH ALARM
* 164455    09/01/81   2      4 53761   2AF-15                           2-AF-15 INSULATION
* 164455    01/29/82 002      3 24040   2AF 15 BOTTOM STONE              REPLACE STONE
* 164456    02/08/80   2      2 13700   02AF-16 VENT LINE                02AF-16 VENT LINE IS STOPPED UP PLEASE
* 164456    10/01/80 002      3 51747   2AF-16 NUVA FEEDER               2-AF-16 VENT LINE
* 164456    11/27/80  02      2 21764   2AF16 NUVA FEEDER                UNSTOP VENT LINE
* 164456    11/27/80 002      3 21771   2AF-16 NUVA FEEDER               TROUBLE SHOOT CIRCUIT
* 164456    02/11/81  02      2 52543   2AF16                            2AF-16
* 164456    09/01/81   2      4 53762   2AF-16                           2-AF-16 INSULATION
* 164457    01/24/80   2      2 16999   VENT VLAVE ON HOPER 2AF16        REPLACE OR ADJUST VENT VALVE SEATON 2AF1
* 164457    08/05/80 002      2 65011   2AF17 HOPPER STONES              2AF17 STONE
* 164457    09/02/80 002      2 51604   2AF16 NUVA FEEDER                2AF-16 VENT LINE
* 164457    12/12/80 002      3 52099   2AF17 FLYASH HOPPER              2AF-17 VENT LINE LEAK
```

Figure 8-8. Example of repair/service history.[2]

8.7 V-I CURVES

Air-load tests and gas-load V-I curves are a fundamental part of ESP maintenance and troubleshooting. The V-I curve represents the voltage-current relationship on the secondary side of the T-R set. Details of the shape of the curve, corona initiation, and the termination point are controlled by the physical condition of the ESP and gas stream conditions. Preparation of a baseline or reference V-I curve for each ESP field under ideal or optimum conditions will permit evaluation of changes in internal conditions and operating conditions at a later date.

Two types of V-I curves can be produced--air-load or gas-load. The air-load test, as implied by the name, is prepared when the ESP is not receiving particulate matter or hot gas from the process. The gas-load test is conducted when the ESP is receiving flue gas and particulate (i.e., during normal operation). Procedures for producing and utilizing both types of V-I curves are discussed in Sections 3.3 and 4.1, and will not be repeated here.

8.8 PROCEDURES FOR HANDLING MALFUNCTION

Many malfunctions are of an emergency nature and require prompt action by maintenance staff to reduce emissions or prevent damage to the unit. On some units, predictable but unpreventable malfunctions can be identified; such malfunctions include hopper pluggages, wire breaks, T-R set trips, shorts, and conduit arcing. These problems as well as corrective actions are discussed in Sections 4.2 and 4.3.

An effective O&M program should include established written procedures to be followed when malfunctions occur. Having a predetermined plan of action reduces lost time, increases efficiency, and reduces excessive emissions. The procedures should contain the following basic elements: malfunction anticipated, effect of malfunction on emissions, effect of malfunction on equipment if allowed to continue, required operation-related action, and maintenance requirements or procedure. Examples of malfunction procedures are presented here.

8.8.1 Example 1 - Foreseeable Malfunction

An example of a foreseeable malfunction that cannot be prevented is hopper pluggage. Although the short-term effect on emissions is not critical, if the pluggage is allowed to continue, the ash will overflow the hopper and back up into the electric field. This will cause a trip-out of the T-R set, which in turn, may cause increased emissions. Although the T-R trip does not cause damage initially, overflow into the electric field can cause a movement in plate or wire frame alignment. Because the impact of the hopper pluggage increases while the time required to clear the problem increases, the procedure for taking action should depend on the extent of the problem. A T-R set trip should not be the first indication of hopper pluggage. Pluggages should be identified through operator inspection, evacuation vacuum charts, etc.

If the problem can be cleared before the high hopper level alarm sounds, operations will not be involved. If the pluggage is significant, operations may be requested to reduce the load (i.e., reduce the particulate matter collection rate) or deenergize the field to reduce particulate matter collection. Obviously, modifications will be made to the procedure depending on the location of the hopper pluggage (inlet/outlet), level of dust in the hopper when the pluggage is identified, and the time required to make repairs.

8.8.2 Example 2 - Internal Malfunction

When an ESP malfunction requires internal repairs, one chamber of the ESP may have to be deenergized. For emission reduction through the remaining chambers, a process reduction may be specified to keep the superficial velocity near design values.

8.8.3 Example 3 - Extensive Malfunction in T-R Set

A T-R set malfunction that involves extensive repairs (rectifier/transformer, etc.) taking several weeks or months would require a field to be out for an extended period, which would result in increased emissions. If adjacent T-R sets have sufficient capacity (secondary current), the isolated field can be jumped to an active energized section. This jump is made internally between wire frames.

8.8.4 Example 4 - Isolation of Portion of T-R Set

Malfunction procedures should include the isolation of shorted electrical sections down to the smallest possible area. This may involve the isolation of one-half of the T-R set if it is double-half or full-wave. Records should be maintained showing any isolation, jumping or other preventive measure that may have been taken.

REFERENCES FOR SECTION 8

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2. Rose, W. O. Fossil Maintenance Documentation at Duke Power Company. In: Proceedings Conference on Electrostatic Precipitator Technology For Coal-Fired Power Plants. EPRI CS-2908 - April 1983.

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APPENDIX A

ESP APPLICATIONS IN CEMENT INDUSTRY

BACKGROUND

The manufacture of portland cement is basically a calcining operation in which rock and earth are mixed and burned slowly in a rotating kiln. The burning drives off carbon dioxide (CO_2) and leaves a clinker product that is composed primarily of calcium silicates.[1] The basic raw materials used in portland cement manufacturing are calcium carbonate, silicon oxide, alumina, ferric oxides, and small amounts of sulfate, alkali, and carbonaceous materials.[2]

The rock and earth from the quarry are crushed, screened, and ground to the appropriate size for mixing and blending before they are fed (dry or as a slurry) into the back or feed end of the kiln. Dry process feed usually contains less than 1 percent water by weight. A typical wet process feed contains 34 to 40 percent water by weight. The electrical characteristics of the particulates generated by these two processes vary widely.

Figure A-1 is a flow diagram of the portland cement process. As shown, crushing sometimes takes place in two or three stages. Crushing, screening, and grinding operations are typically vented directly to the atmosphere and are potential sources of particulate matter emissions. The emission rate depends on the kind of raw material and its moisture content, the characteristics of the crusher, and the kind of control equipment used (usually fabric filters) and its operation and condition.

The rotary kiln is the major source of emissions at a portland cement plant. The rotary kiln has three stages of operation: feed, fuel burning and clinker cooling and handling.[3] The raw materials are fed into an elevated and inclined refractory-lined steel cylinder that rotates at approximately 50 to 90 revolutions per hour. As the kiln rotates, its slightly

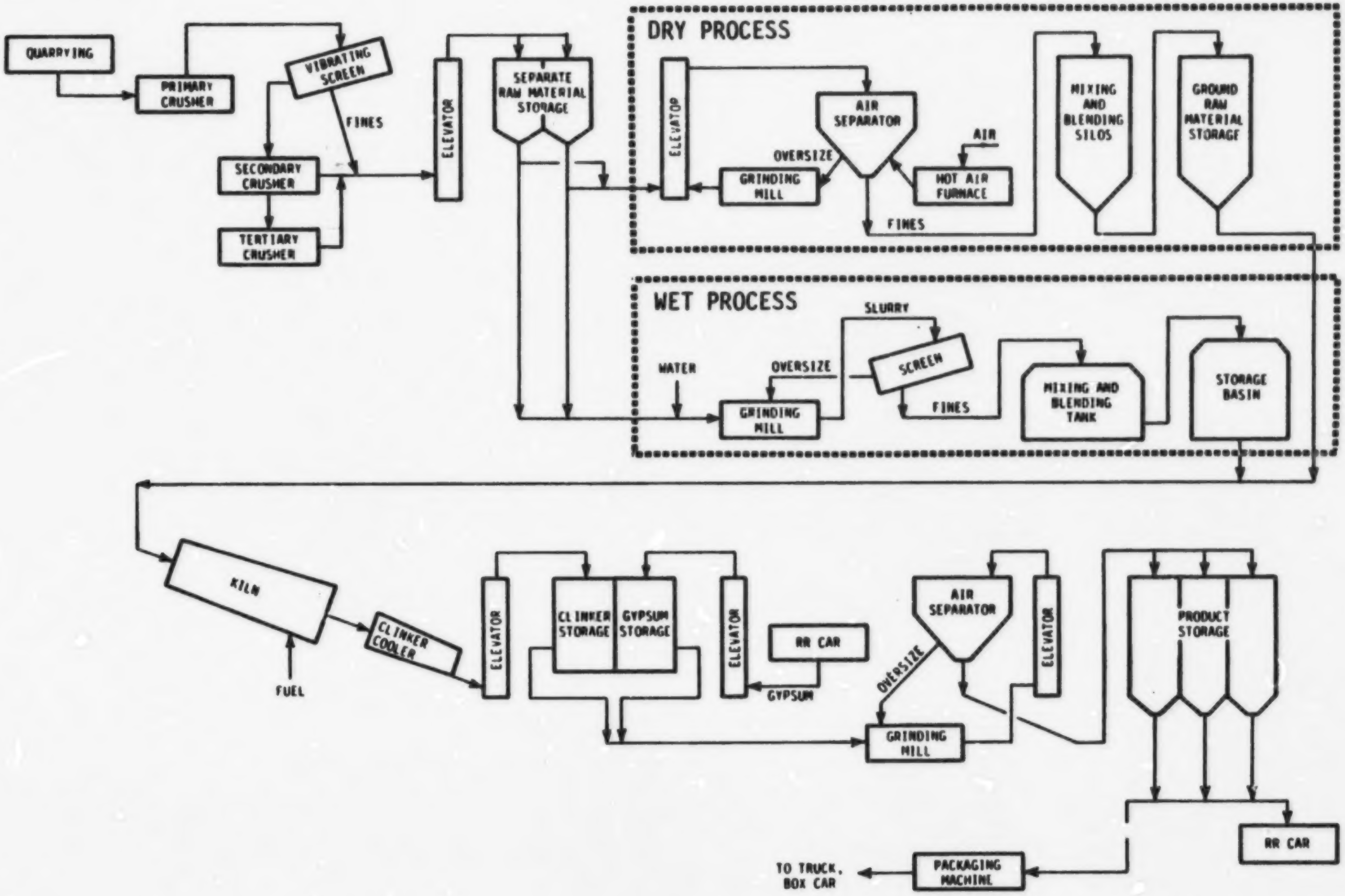

Figure A-1. Schematic diagram of portland cement process flow.[3]

inclined position causes the feed to travel slowly downward and be exposed to increasing heat. Water is evaporated from the feed with the aid of heat exchangers. As the temperature increases, organic compounds are volatilized. At about midsection of the kiln, calcium and magnesium carbonates are decomposed and CO_2 is liberated. Calcium oxide and magnesium oxide are also formed. At 2700°F, approximately 20 to 30 percent of the charge is converted to liquid. It is while the charge is in this state that the chemical reactions proceed and the material turns incandescent.

The kiln consumes large quantities of fuel and is a large source of particulate matter emissions. Design features that reduce particulate matter emissions include the use of larger kiln diameters at the feed end and the addition of suspension preheaters.

Depending on its alkali content, the dust collected in the initial stages of the kiln operation often can be returned to the kiln. This reduces disposal problems and effects a cost savings in raw material. The dust may be returned directly by mixing it with the kiln feed and introducing it in a parallel feeder. Another method of returning the dust is by insufflation; the dry dust is returned to the burning zone either through the fuel pipe or by a separate pipe running parallel to the fuel pipe.[2]

The clinker from the kiln rolls into a clinker cooler. As the clinker cooler reduces the temperature of the clinker, it recovers the heat from the clinker to preheat the primary or secondary combustion air in the kiln. After the clinker is cooled, it may be taken to a storage area or transferred to finishing mills. The finishing mills are usually rotary ball mills. Sometimes these mills are sprayed with water to keep them sufficiently cool and to minimize dehydration of the gypsum, which is added at a rate of 5 percent, to control setting times.

Although the design of the equipment used in the cement process is not complex, several design features or operating characteristics can affect the amount and quality of material found in the effluent. These include:

- Extra fine grinding in the mills seems to generate more particulate matter in the effluent.
- Higher speeds of kiln rotation tend to generate more particulate matter.

- The type and size of chain section used in the kiln (as a heat exchanger and to provide intimate mixing of the wet slurry and waste gases) can either increase or reduce the quantity of released dust. Short sections of dense curtain chains might help reduce dust generation, whereas loop systems might allow more to be released.
- More draft than required tends to generate more dust carryover.
- Long dry-process kilns usually contain a minimal chain section, but flue gas temperatures are usually controlled at the back end by water sprays and dilution air on the older units.
- Recently, the industry has begun to use several new types of heat exchangers (cyclone preheaters, for example) on dry-process rotary kilns; these new exchangers preheat the raw feed by intimate mixing with the waste gases.
- Insufflation (the method of returning collected material back into the kiln by blowing it into the burner flame or including it with the pulverized coal) has been processed less frequently in recent years. Although beneficial in some ways, this method has caused some difficulties in the ESP by increasing the circulation of dust concentrations and causing higher alkali content.

PROCESS VARIABLES AFFECTING ESP PERFORMANCE IN CEMENT INDUSTRY

The major application for ESP's in the cement industry is for collection of the particulate matter leaving the feed or back end of the kiln. Both wet- and dry-process rotary kilns have successfully used ESP's. Several key process variables, however, effect ESP performance. These include:

- Concentration of particulate matter in the kiln gas
- Size distribution of the waste dust
- Moisture content of kiln gases
- Gas temperature of kiln gases
- Alkali and chloride content of the particulate matter in the kiln gas.

Based on a number of field measurements of waste dust in the discharge gases of wet process kilns, the particulate emissions range from 1.5 to 6.0 gr/acf or 30 to 50 lb dust per barrel of clinker. Emissions from the dry process will normally be 10 to 20 percent higher at similar kiln production rates.[1]

Large particles leaving the back end of the kiln are usually separated out in the dust plenum, which serves as a drop-out chamber. Thus, the material entering the ESP is finer in size than fly ash, but it exhibits a similar heterogeneous distribution.

Moisture levels in the wet process gas stream closely approximate the water percentage of the slurry in a tight system. Moisture in the dry process kiln depends primarily on the quantity of water spray conditioning used to control back-end temperatures. Moisture levels are also increased by the combustion of fuel. If the moisture level rises above 10 to 20 percent, care must be taken to maintain the ESP temperature above the dewpoint to avoid potential corrosion problems. Where precalciners are used, however, the moisture level should be approximately 4 to 5 percent to ensure adequate ESP performance.

The major effects of temperature are reflected in the modification of the electrical characteristics and the reactions of the particles as they are deposited on the plates. The electrical characteristics of almost all particulate matter collected by an ESP vary widely in the temperature range of 200° to 750°F. At the lower end of the range, electrical characteristics are affected by condensation and surface leakage; at the higher end of the range, they are affected by conductivity changes in the bulk material. The real effects at any given temperature depend on the moisture level and chemical composition of the particulate matter. The greater concern, however, is whether the ESP is operating in the critical temperature zones for effective control of the particulate matter. The most critical range for ESP cement applications is 350° to 400°. Within these critical zones, electrical readings may vary with temperature shifts as small as 10° to 15°F.

The alkali compounds (potassium and sodium), sulfur, and chloride are considered the volatile components. When the alkali material in the feed slurry is heated to approximately 1000° to 1500°F, it vaporizes and becomes entrained in the kiln combustion gases. As the gases reach the feed end of the kiln, their temperature is lower (because of the heat exchange with the chains and the heat loss resulting from water evaporation in the slurry) and the volatile compounds condense on the feed slurry nodules. The normal movement of the slurry down the kiln returns the volatiles to the hotter area of the kiln, where they are revaporized. This vaporizing/condensing cycle continues until an equilibrium is reached between the feed alkali and the final loss from the kiln through the clinker product and the particulate in the exhausted combustion gases.

EFFECTS OF PARTICULATE CHEMISTRY ON ESP PERFORMANCE

The condensed alkali compounds appear as submicron size or fine particles, composed primarily of potassium hydroxide, potassium chloride, potassium sulfate, sodium hydroxide, sodium sulfate, and sodium chloride. The specific chemistry of the alkali compounds depends on kiln temperature, slurry chemistry, and back-end temperature. Chemical properties of typical volatile components are provided in Table A-1 and Figure A-2. The volatile compounds also condense on larger particles that are entrained by the flue gases in the drying slurry feed materials. These larger particles, which are primarily $CaCO_3$, CaO, and SiO_2, are chemically close to the composition of the feed slurry.

TABLE A-1. CHEMICAL PROPERTIES OF VOLATILE COMPONENTS OF PARTICULATES FROM CEMENT KILN PROCESSING

	K		Na	
Compound	Melting point,°C	Boiling point,°C	Melting point,°C	Boiling point,°C
Oxide	Decomp.	350	Sublim.	1275
Carbonate	894	Decomp.	850	Decomp.
Sulfate	1074	1689	884	-
Chloride	768	1411	801	1440
Hydroxide	360	1320	328	1390

The emissions from the kiln typically form a bimodal particle size distribution with a submicron size fraction and a supermicron size fraction. Although an ESP is effective in collecting both particle size fractions, the probability of collecting the larger particles is greater. The larger nonalkali particles are collected in the front fields of the ESP, whereas the

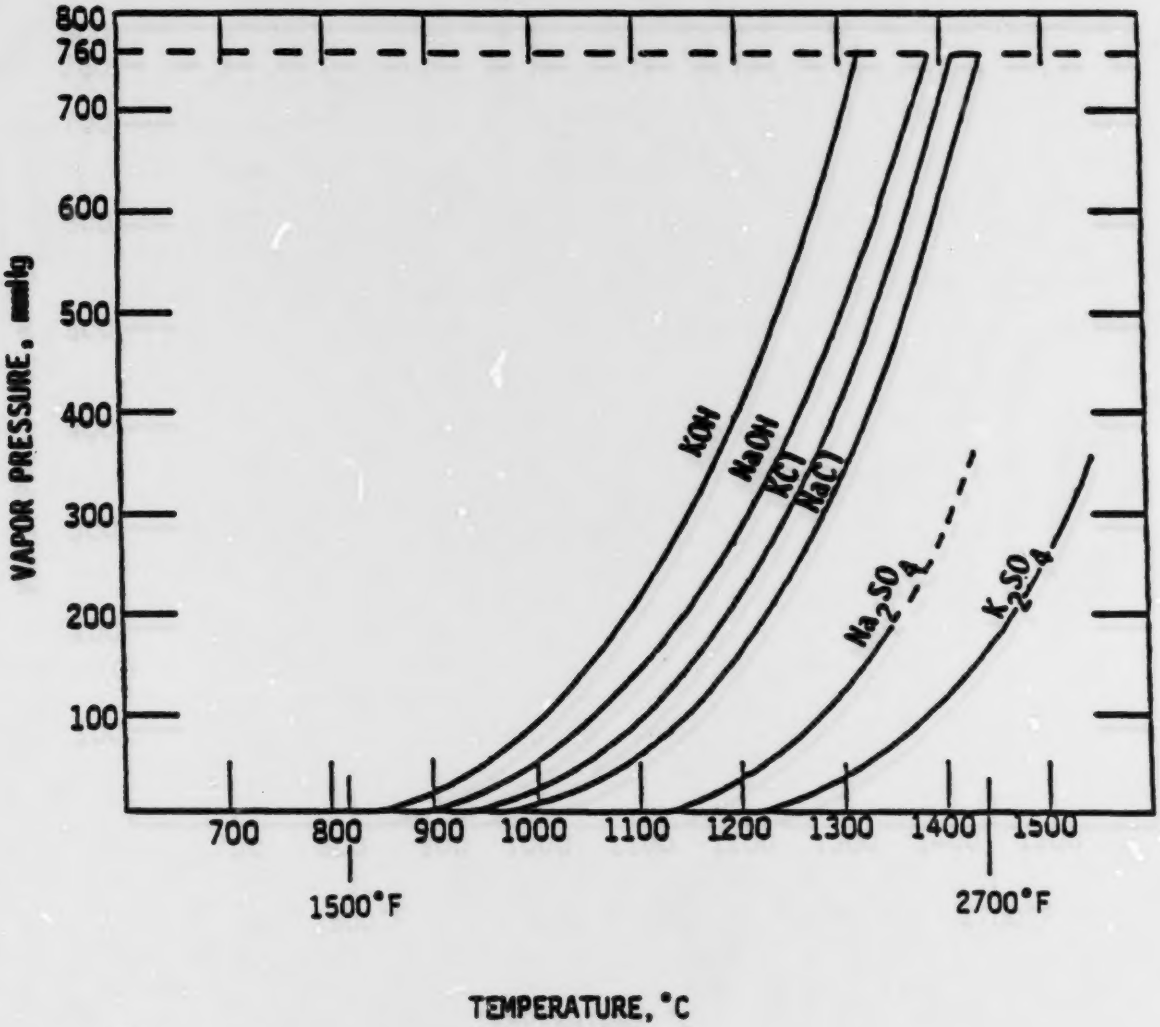

Figure A-2. Chemical properties of alkali volatile materials in cement kiln processing.

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harder-to-collect finer alkali particles tend to pass through the inlet fields. A typical analysis of the dust found in ESP hoppers shows that the alkali content increases from inlet to outlet fields.

Table A-2 presents typical composition data for successive fields on a wet-process kiln ESP. Figure A-3 shows the decrease in nonalkali particulates (CaO and SiO) as a percentage of total dust composition in successive fields of a typical ESP.[4] The enrichment of alkali particulates (Na_2O, K_2O, and SO_3) results primarily from the high removal rate for nonalkali materials in the inlet field. The close association of K_2O and SO_4 is expected because a major portion of the alkali particulates is composed of potassium sulfate (Na_2SO_4). This increasing percentage is not always found, especially if most of the alkali condenses onto larger nonalkali particles. In this case, the particle size/chemistry is more homogeneous and the ESP does not segregate the dust chemically by fields.[5]

TABLE A-2. TYPICAL COMPOSITION OF DUST COLLECTED IN SUCCESSIVE FIELDS OF AN ESP SERVING A WET PROCESS CEMENT KILN (ROCK FEED)[4]

Chemical compound	Composition, %				
	Inlet	Field 1	Field 2	Field 3	Field 4
Na_2O	0.47	0.50	0.74	0.98	1.72
K_2O	5.80	7.00	12.05	19.80	35.80
Li_2O	0.34	0.24	1.00	1.64	2.16
MgO	0.41	0.85	1.09	0.20	0.12
CaO	41.98	43.26	39.41	29.09	8.19
Al_2O_3	7.98	6.15	2.14	2.15	1.75
SiO_2	13.48	12.80	11.72	8.76	3.72
Fe_2O_3	1.84	1.90	1.84	1.44	0.63
LOD	19.91	18.96	17.89	14.08	7.85
SO_3	6.84	7.19	11.15	20.31	37.03
TiO_2	0.26	0.25	0.22	0.17	0.06

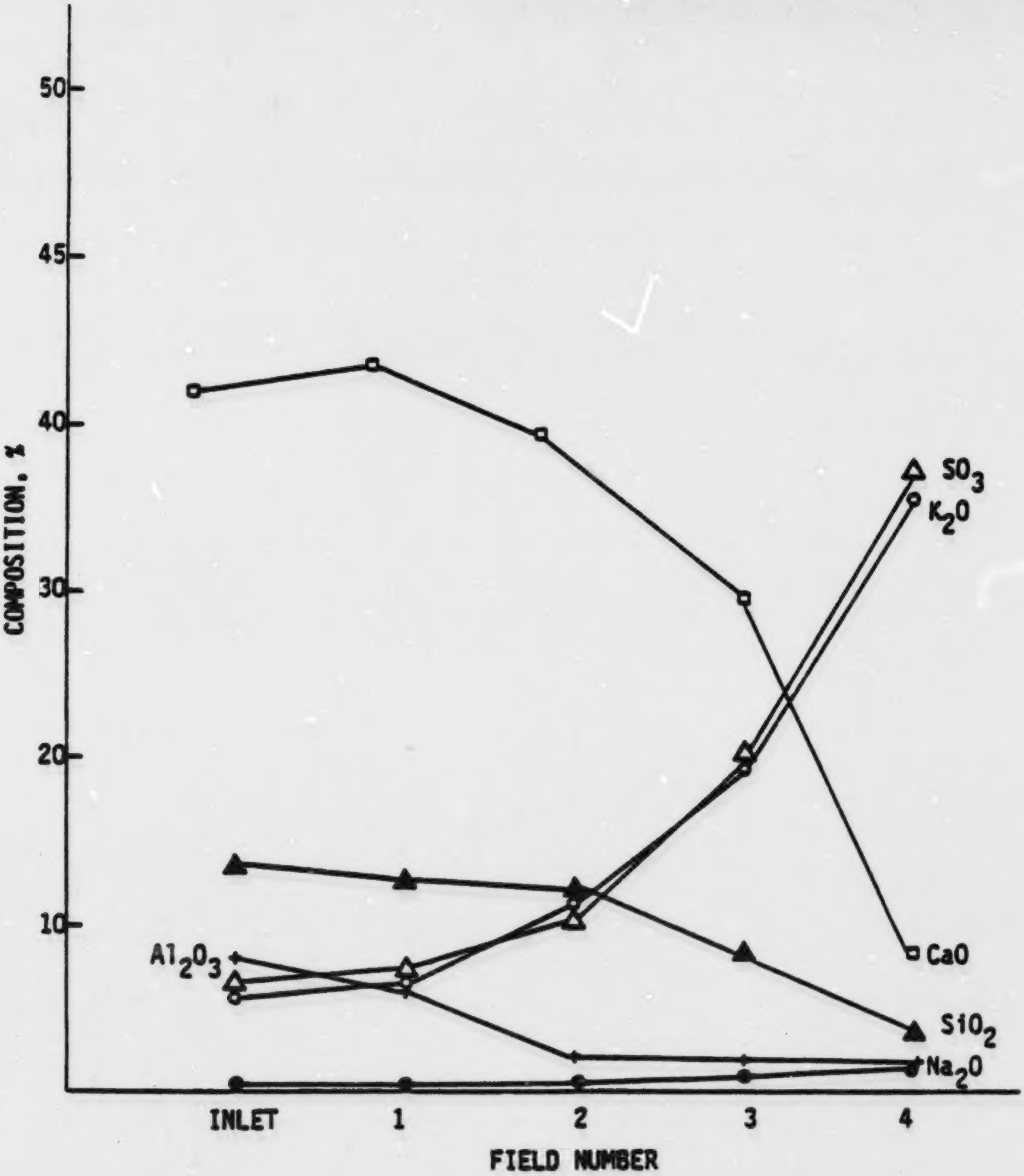

Figure A-3. Selective removal of nonalkali particulates in inlet fields of ESP and enrichment of alkali dust in outlet fields.[5]

The chemistry of the particulates also affects their resistivity. Soluble alkali components (Na_2SO_4 and NaCl) have proved to be effective in reducing resistivity.[6] Resistivity is also a function of temperature and moisture of the gas stream (Figure A-4).[7] Figures A-5 through A-9 show how cement dust resistivity changes in successive fields of a typical ESP as the alkali content increases.[8]

Process yield can be increased by returning low-alkali ESP dust to the kiln. The intent is to recover the carbonates, oxides, aluminates, and ferrous compounds. The dust may be returned by several methods: insufflation at the burner end, dry dust at the feed end, and scoops at mid-kiln. It is common practice to return the dust collected from the front ESP fields to the kiln by one of these methods.

As the alkali material in the slurry becomes vaporized, it enters the "volatile recirculation system" within the kiln. The net effect of this recirculation system is to increase the fine particle fraction of the loading to the ESP. The nonalkali materials also become suspended in the flue gases and are exhausted to the ESP. The equilibrium obtained by the combined recirculation of alkali and nonalkali dust increases the inlet loading to the ESP by a factor of 2 to 3 above that when nonrecirculation does not occur. The amount of insufflated dust that may be used is limited by the allowable alkali content in the finished cement.

KEY ESP DESIGN PARAMETERS

One key design parameter that has proved to be very useful in evaluating ESP performance is the specific collection area (SCA), which is the total collecting surface divided by the gas flow rate. Typical SCA values range from 300 to 400 ft^2/1000 acfm for wet-process ESP's,[9,10] and from 200 to 500 ft^2/1000 acfm for dry process ESP's.[10]

Since 1960, there has been a general increase in the design SCA for ESP's installed on wet-process kilns (Figure A-10). Although design SCA's for ESP's applied to dry-process kilns have also increased in general, in some situations in the late 1970's and early 1980's, the SCA was actually

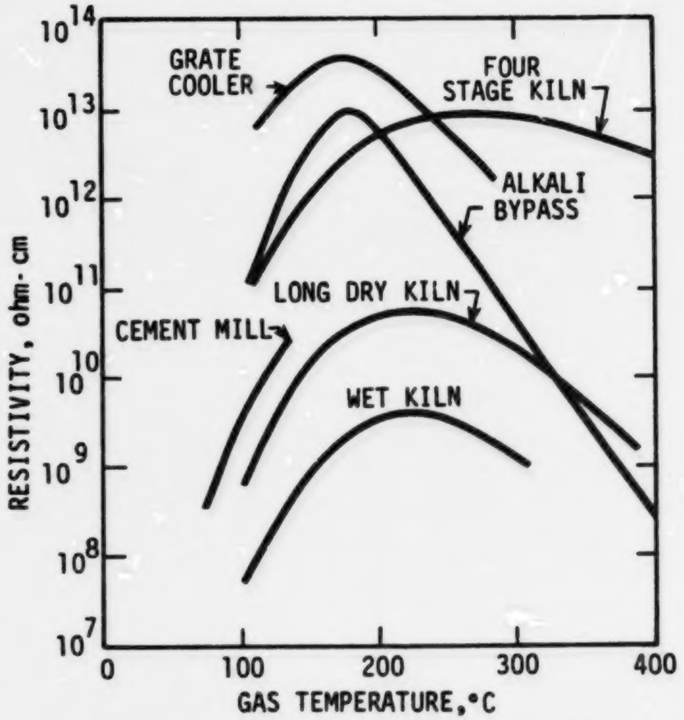

Figure A-4. Resistivity of dust from cement making processes.[7]

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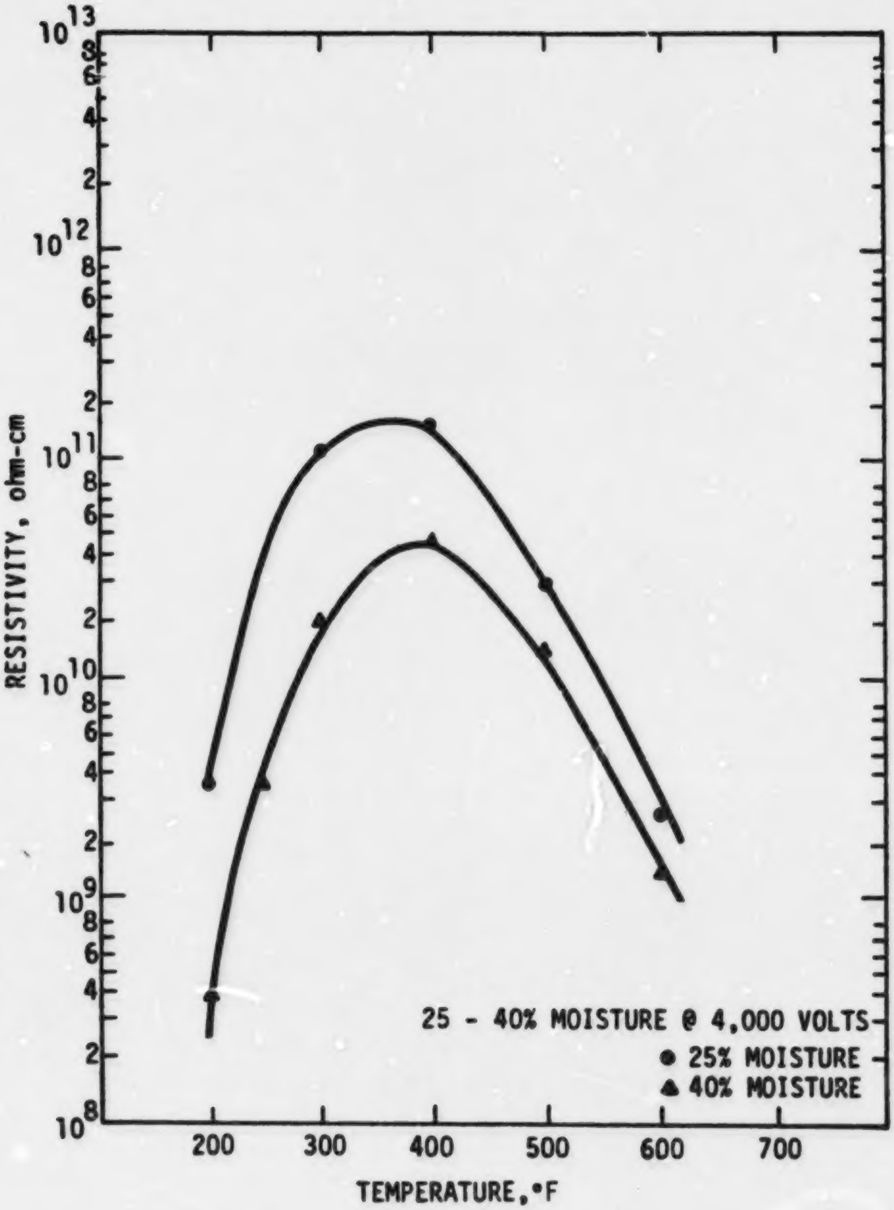

Figure A-5. Typical resistivity of cement dust collected at the inlet of an ESP serving a wet-process cement kiln (rock feed) as a function of moisture content.[5]

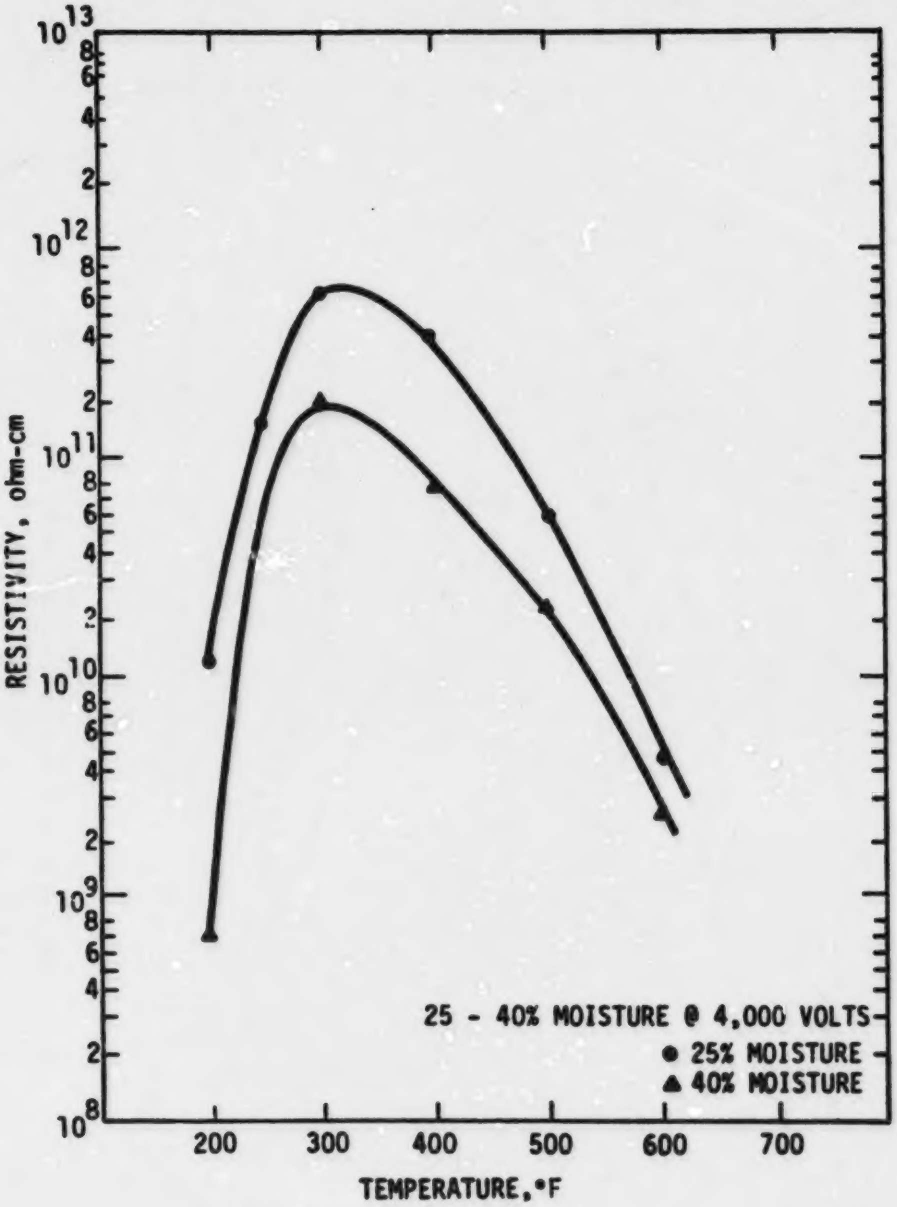

Figure A-6. Typical resistivity of cement dust collected in the first field of an ESP serving a wet-process cement kiln (rock feed) as a function of moisture content.[5]

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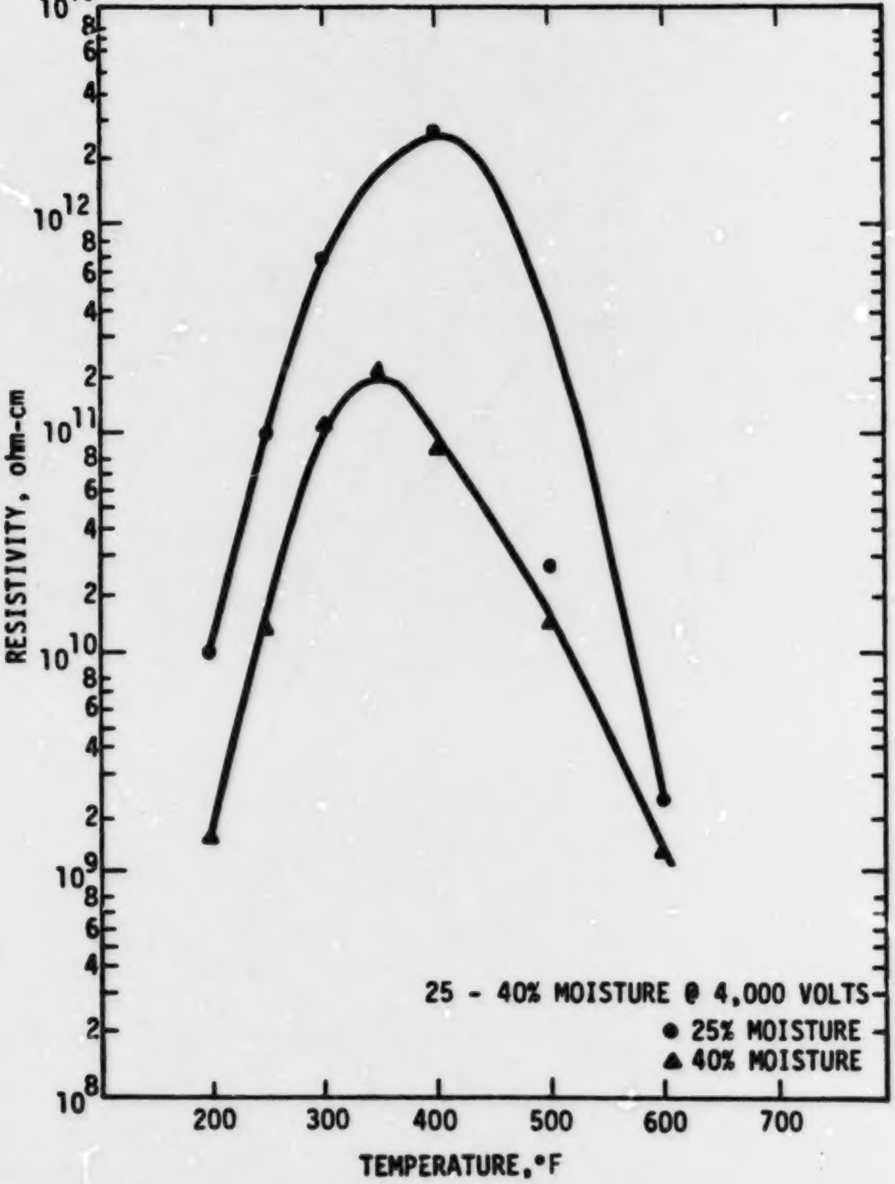

Figure A-7. Typical resistivity of cement dust collected in the second field of an ESP serving a wet-process cement kiln (rock feed) as a function of moisture content.[5]

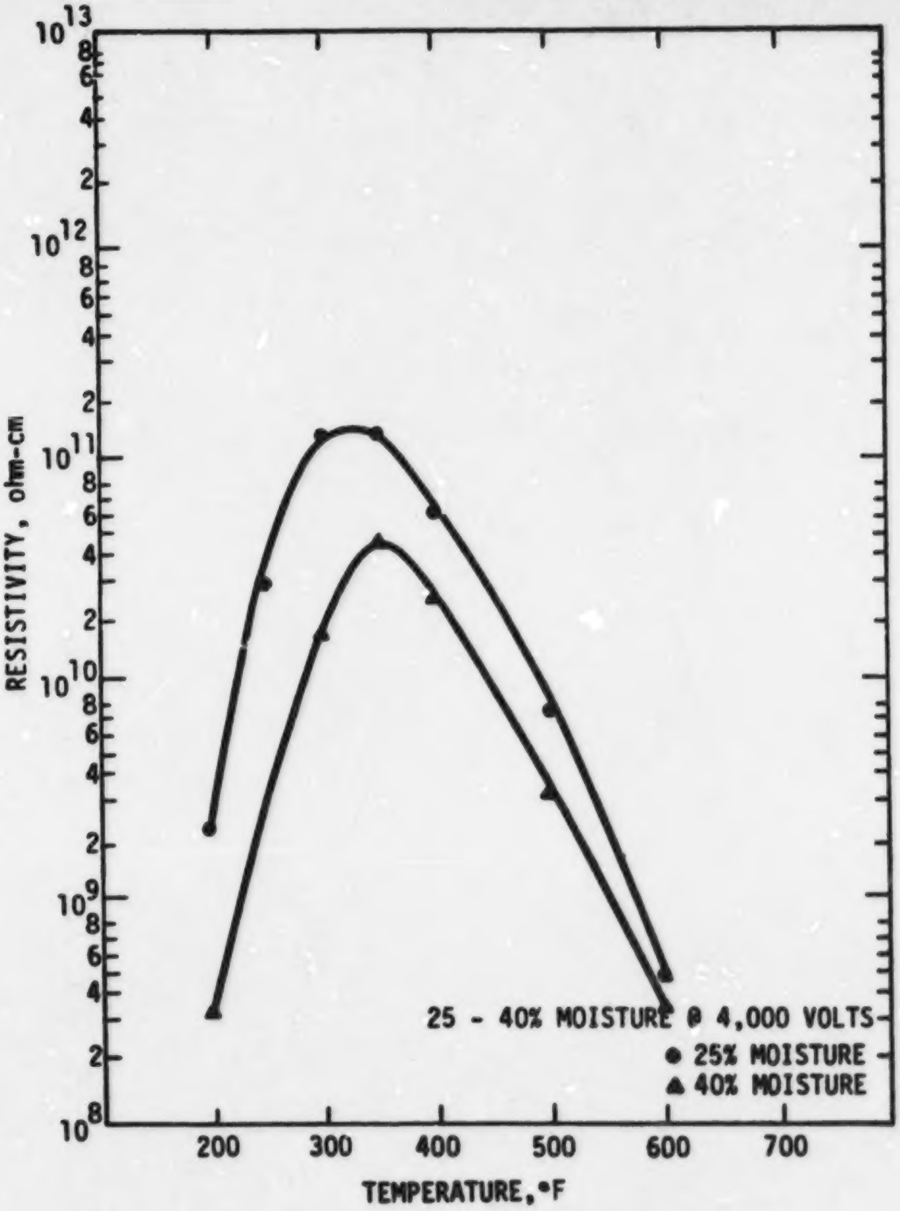

Figure A-8. Typical resistivity of cement dust collected in the third field of an ESP serving a wet-process cement kiln (rock feed) as a function of moisture content.[5]

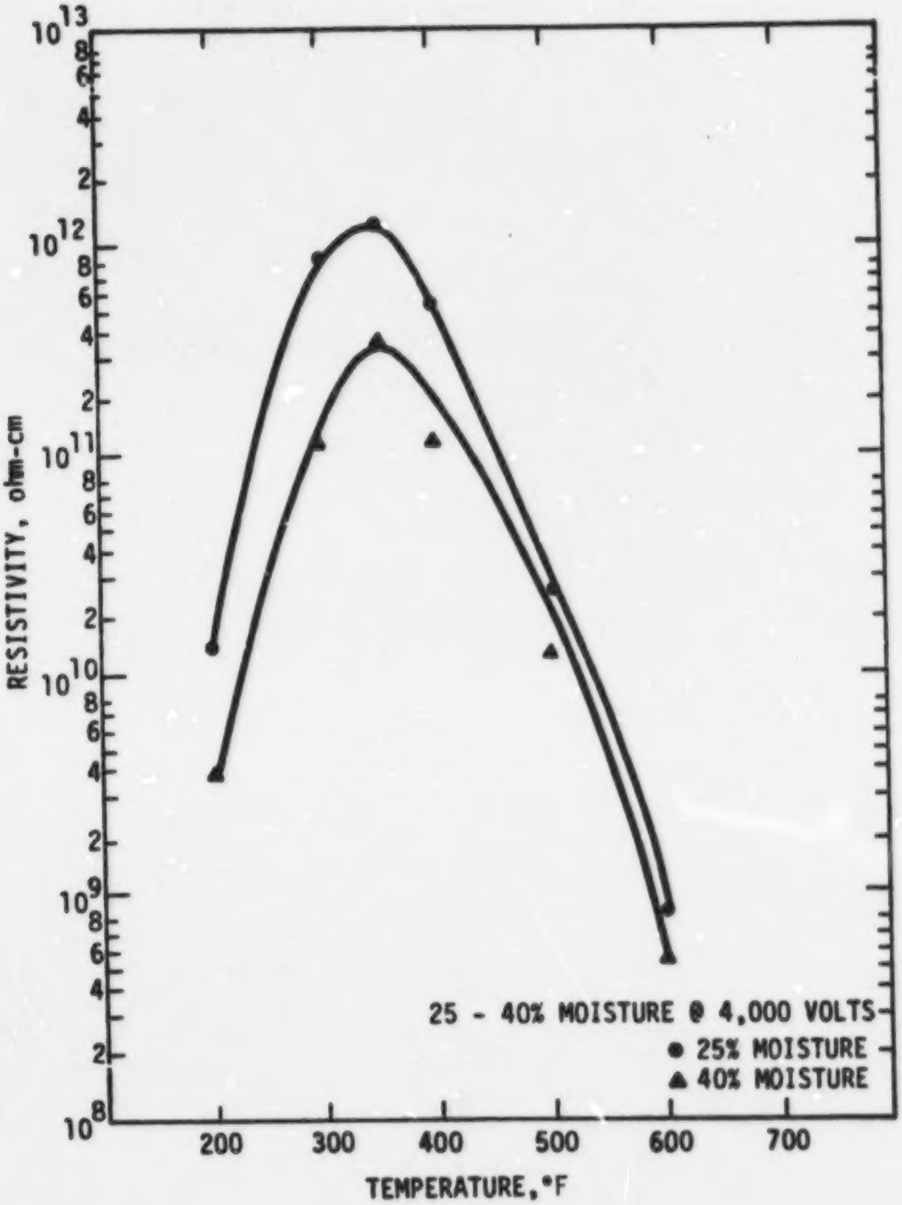

Figure A-9. Typical resistivity of cement dust collected in the fourth field of an ESP serving a wet-process cement kiln (rock feed) as a function of moisture content.[5]

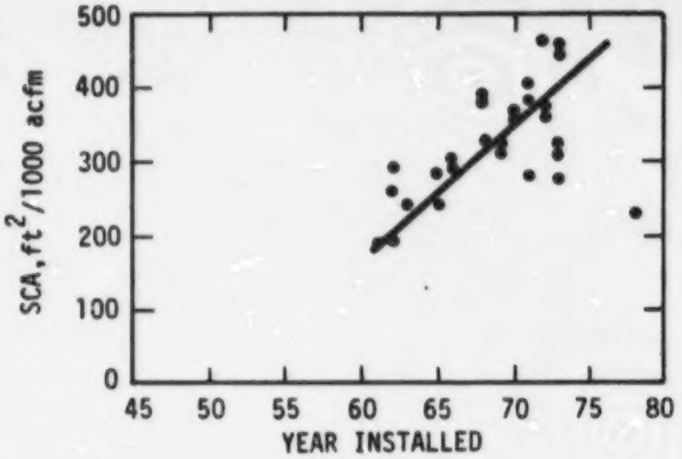

Figure A-10. Design SCA vs. year installed for wet-process kilns.

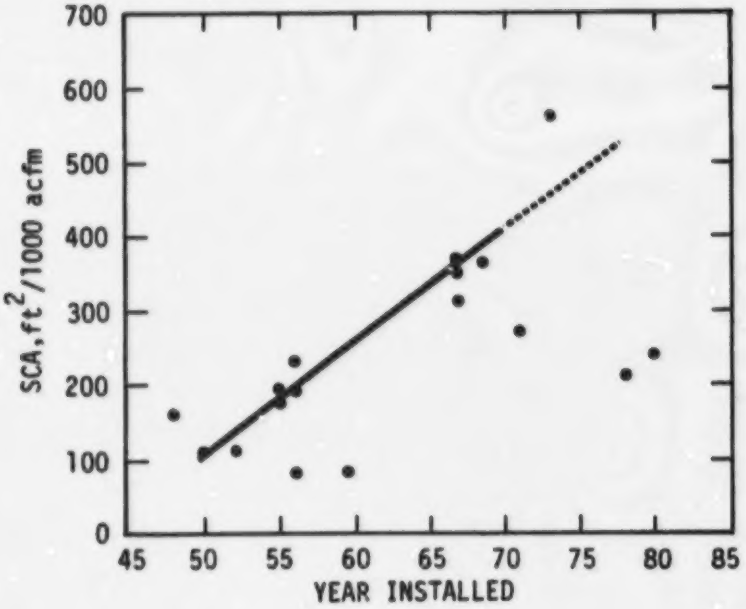

Figure A-11. Design SCA vs. year installed for dry-process kilns.

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decreased (Figure A-11). The purpose of larger SCA's was to increase collection efficiency. Figures A-12 and A-13 present the design collection efficiencies versus SCA's for wet- and dry-process kilns. In general, SCA's in the range of 300 to 400 ft^3/1000 acfm are needed to achieve 99+ percent control efficiency.

OPERATING PRACTICES THAT AFFECT ESP PERFORMANCE

The grinding heat in a cement mill is almost equal to the power consumption of the mill motor. Assuming that the clinker temperature is the same as that of the finished product, all of the grinding heat has to be removed. Approximately 20 percent of this heat may be dissipated by radiation; the remaining 80 percent is usually removed by using air as the cooling medium, by evaporation of water injected into the mill, or by a combination of these methods.

If air only is used for cooling, a great amount of air is required. Because the air will be dry, electrostatic precipitation will be less effective. Injecting water into the mill for cooling and aiming at a water content in the vent air corresponding to a dewpoint of 60°C can reduce the required air volume by a factor of 5. Operating conditions for the ESP are ideal at a dewpoint of 60°C.[7].

At the startup of a cold mill, no water injection is possible until the cement temperature has risen above 110°C. During this time, ESP performance is often less than ideal because the dewpoint of the air from the mill is too low. When this lower efficiency is not acceptable, a special method can be used that automatically keeps the dust loss low during the startup period. The method involves reducing the air flow through the mill by approximately 40 percent during the period with no water injection. The principles of this method are as follows:[7]

- The ESP is energized before the fan and mill are started; this suppresses initial dust puffs.
- When the fan is started, the air flow through the mill is reduced to the minimum required to keep the mill inlet dust-free. This reduces the air velocity in the mill and ESP and lowers the dust concentration.

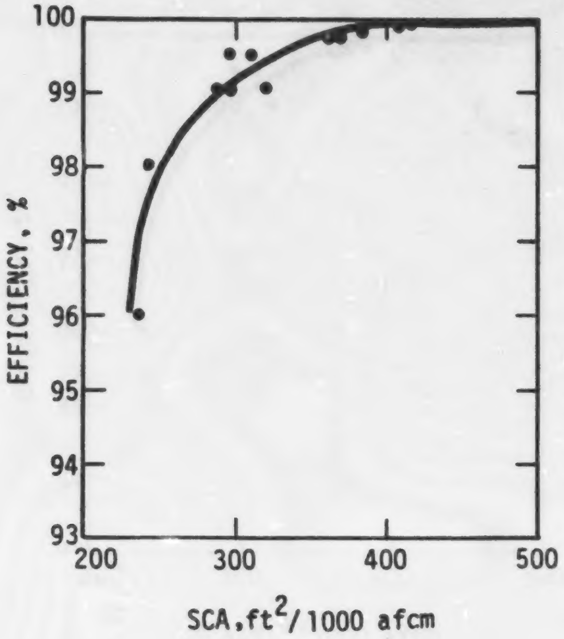

Figure A-12. Design collection efficiency vs. SCA for wet process kilns.

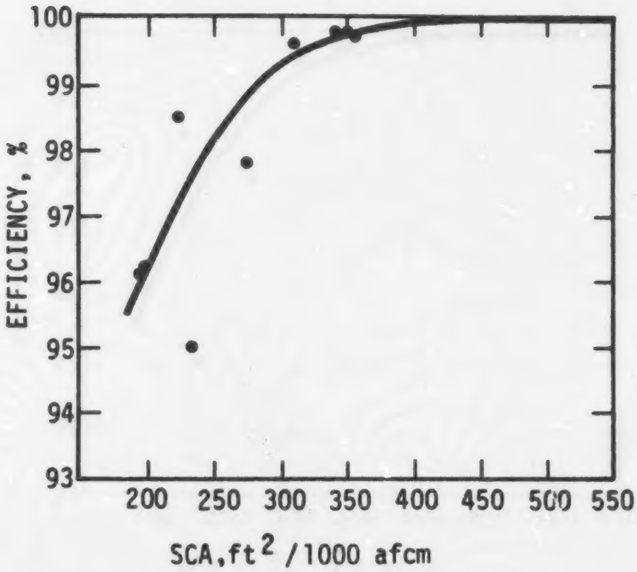

Figure A-13. Design collection efficiency vs. SCA for dry process kilns.

- Startup of the ESP rapping gears is delayed to avoid dust puffs during periods of difficult operating conditions (when dewpoint is low). After a few minutes of operation, the dewpoint rises as a result of evaporation of water from the gypsum and the rapping can begin.

- When the water injection starts, the air flow through the mill is immediately regulated up to a level corresponding to the desired dewpoint for normal cement mill operation, i.e., 60°C.

- An automatic spark rate controller on the high-temperature rectifiers keeps the ESP voltage at optimum level during the varying operating conditions.

- The ESP remains energized and the rapping gears continue to operate for a certain period after the cement mill is stopped; this cleans the air drawn through the system by natural draft.

Figure A-14 shows results from tests run out at a Danish cement plant that used the method just described. Because dust emissions remain low during the startup period in spite of the reduced dewpoint, ESP migration velocity is reduced, primarily because of the reduced air flow through the ESP and the low inlet dust concentration.

Because the resistivity of the dust after a cyclone preheater kiln is usually quite high, a very large ESP is required if the gases are to be treated without water conditioning. Therefore, water conditioning is the rule because it reduces the gas volume, reduces the resistivity of the dust, and increases the dielectric strength of the gas. For these reasons, water conditioning has a very pronounced, positive effect on ESP performance. This is directly reflected in the operating voltage, as illustrated in Figures A-15 and A-16.

Figures A-15 and A-16 show the effect of water conditioning on ESP current-voltage characteristics for a preheater kiln with a conditioning tower and for a preheater kiln with a raw mill. As the water conditioning increases and the gas cools, the ESP voltage rises dramatically and performance improves. Over a wide temperature range, the current-voltage characteristics are almost vertical, or even curve back, which indicates "back-corona" due to high resistivity.[7]

Figure A-17 shows a preheater kiln with a conditioning tower and a raw mill installed in parallel. In this example, the major part of the hot kiln

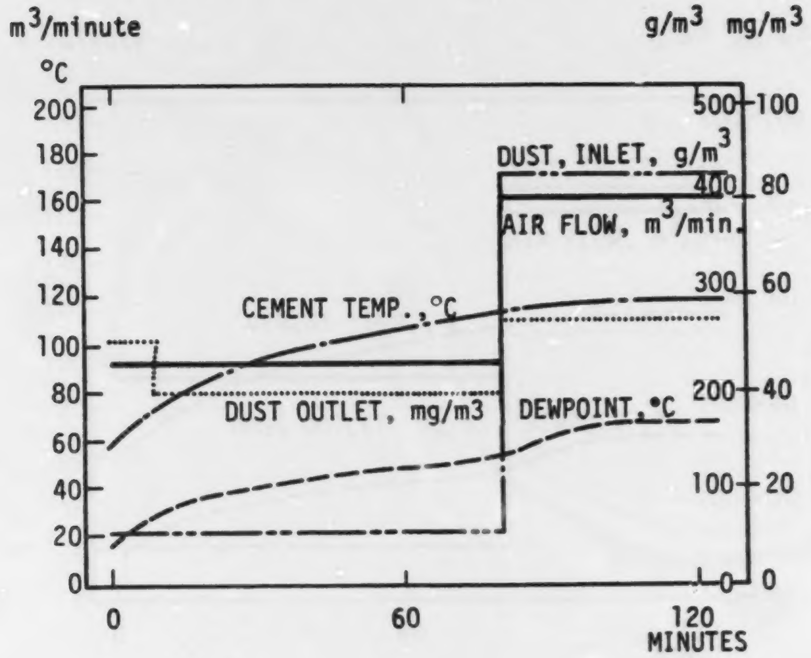

Figure A-14. Automatic control of operating conditions during startup of cement mill.[7]

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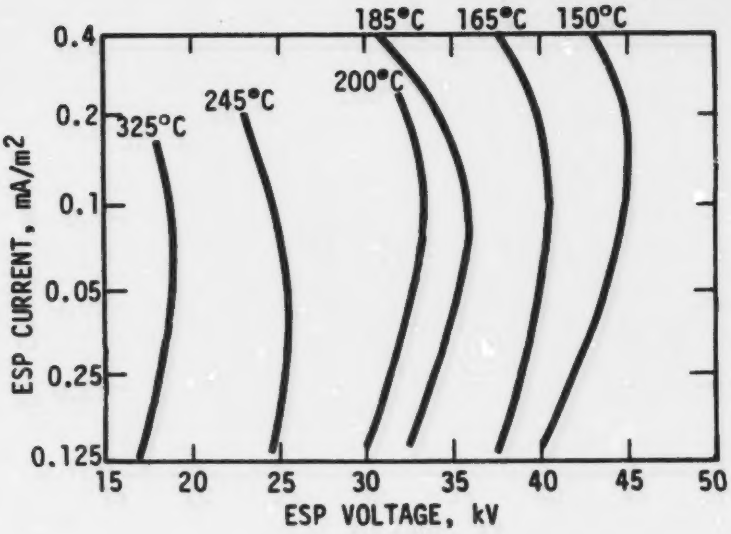

Figure A-15. ESP current-voltage characteristics with varying H_2O conditioning of gas from cyclone preheater kiln with a conditioning tower.[7]

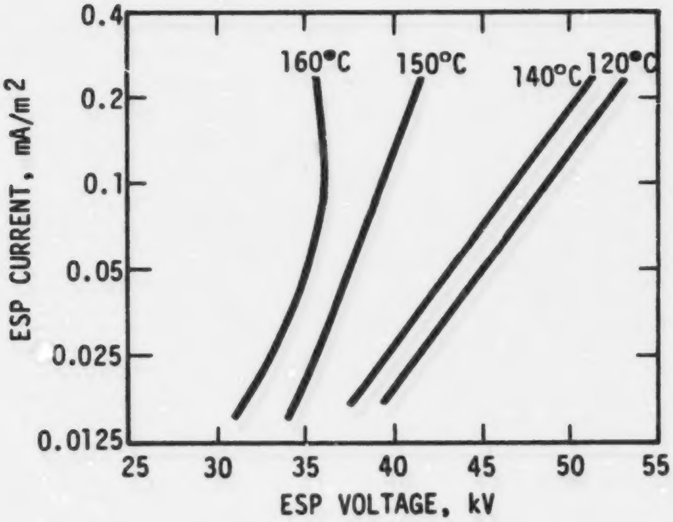

Figure A-16. ESP current-voltage characteristics with varying H_2O conditioning of gas from cyclone preheater kiln with raw mill.[7]

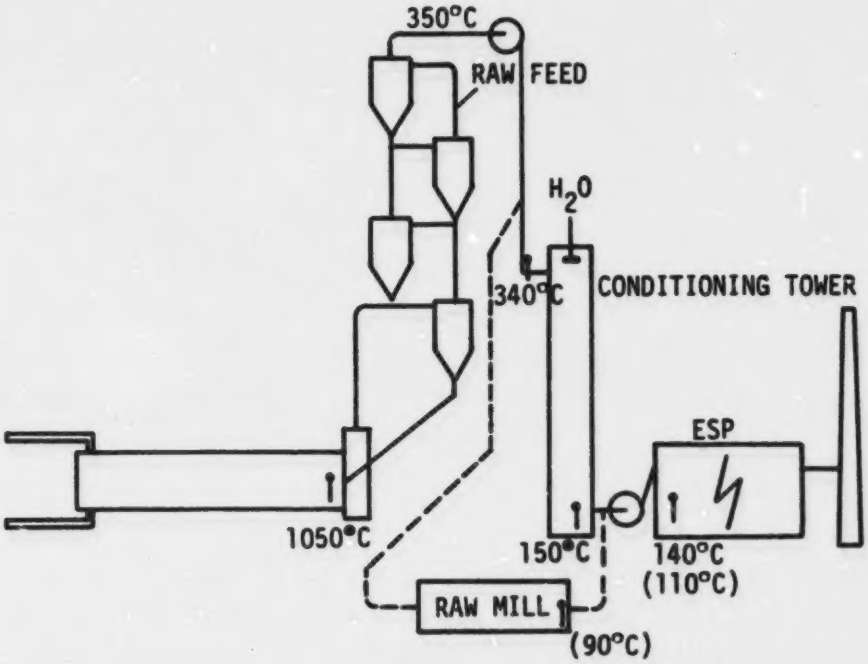

Figure A-17. Cyclone preheater kiln with conditioning tower and raw mill.[7]

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gas is drawn through the raw mill, where the gas obtains moisture from the raw materials. The cooled gas from the raw mill is mixed with the remaining part of the kiln gas, which has been cooled in the conditioning tower, and the gas mixture enters the ESP with an ideal operating temperature and moisture. When the raw mill is stopped, all the kiln gases pass through the conditioning tower, where they are cooled, and acceptable ESP performance is obtained. Thus, good ESP performance can be maintained with the mill in operation or with the mill stopped.

Unstable ESP operation and considerably reduced efficiency can occur, however, in the transition phases between the two modes of operation, especially in connection with startup of the raw mill. When the mill is started, the major part of the gas is diverted from the conditioning tower to the mill. Because the amount of water injected and evaporated in the conditioning tower is controlled by the gas temperature at the tower outlet, it is reduced in proportion to the reduction in gas flow through the tower. This reduction might be accompanied by a minor or perhaps even a major fluctuation of the gas temperature at the tower outlet, depending on the properties of the conditioning tower's automatic regulation equipment. The hot gases drawn through a cold mill must heat the mill and the raw materials before full-level evaporation of water from the mill is reached. The result is a temporary humidity deficiency in the gas stream from the mill, which, when combined with possible fluctuations of the temperature of the gas stream from the conditioning tower, might result in serious deterioration of the ESP performance during and after the changeover phase.[7]

One method that has been used to overcome this problem is to increase the water injection in the conditioning tower while the mill is heating up. This can be accomplished by an automatic, temporary displacement of the set point of the temperature regulator controlling the water injection. For example, the displacement might be of the magnitude -25°C. This method presupposes that the conditoning tower has sufficient cooling capacity to avoid the sludge formation that would normally accompany such a temperature lowering. Another method is to preheat the raw mill by drawing a small hot gas stream through the mill before the startup.[7] A third method involves the use of automatic control and synchronization of damper movement, water injection changes, and mill startup. This method was successfully introduced at a Greek cement plant where increased dust emissions during changeover periods was a problem. Figure A-18 illustrates the results obtained in this case.

The dust from a grate cooler usually has a high resistivity, and the excess air has a low moisture content; nevertheless, the fairly large particle size of the dust makes it easily precipitable, especially if the ESP performance has been improved and stabilized by increasing the moisture content of the excess air. A few percent moisture by volume is sufficient, and such small quantities of water can be injected without difficulty and evaporated in the grate cooler above the grate at the cool end of the clinker bed.[7]

Occasionally, however, a grate cooler may be subject to large operational variations. Rings may form in the kiln and dam up the mix, and when the ring breaks down, excessive quantities of materials flush through the burning zone and enter the grate cooler. When this occurs, the temperature of the excess air may rise to 400° to 425°C.

Compliance with emission standards during periods of temporary unstable cooler operation requires the control of ESP operating conditions. Planning an appropriate control strategy requires detailed quantitative knowledge of the interactions between the operating parameters (gas temperature, moisture content and resistivity) and ESP performance. Figure A-19 illustrates the relationship between resistivity and air temperature and moisture content, whereas Figure A-20 shows the relationship between ESP migration velocity and resistivity.

In Figure A-21, these two relationships have been combined, and the effect of air temperature and moisture content on the migration velocity through the ESP voltage (independent of the resistivity) has been included. Thus, this figure shows the direct relationship between migration velocity and air temperature and moisture content and also the effects of resistivity as the dielectric strength of air effects. The two dashed lines in the diagram indicate the winter and summer limits for ambient air moisture content, and the hatched area represents possible variations in ESP operating conditions without water conditioning, assuming excess air temperature variations from 90°C to 400°C. It should be noted that an area of low migration velocity occurs around 180°C.[7]

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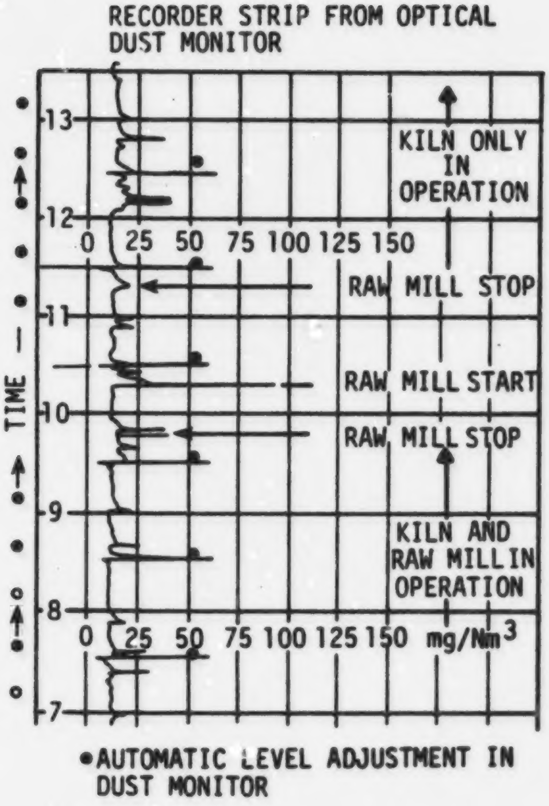

Figure A-18. Dust emissions at a Greek cement plant that used automatic control and sychronization of damper movement, water injection changes, and mill startup to overcome problems during changeovers.[7]

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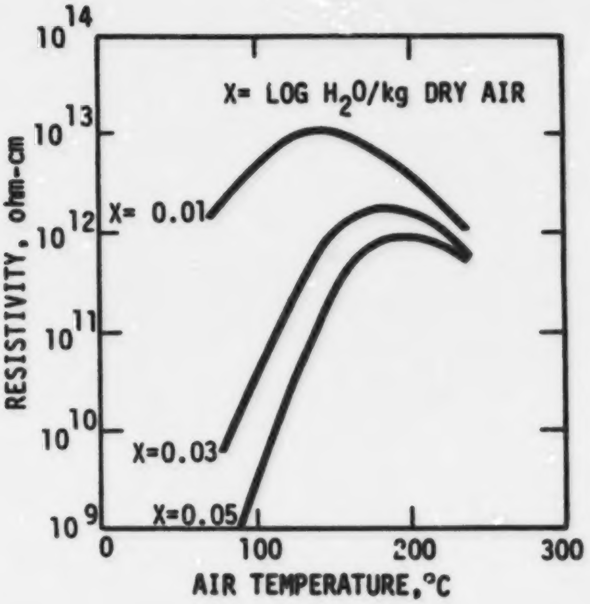

Figure A-19. Resistivity vs. air temperature and moisture content.[7]

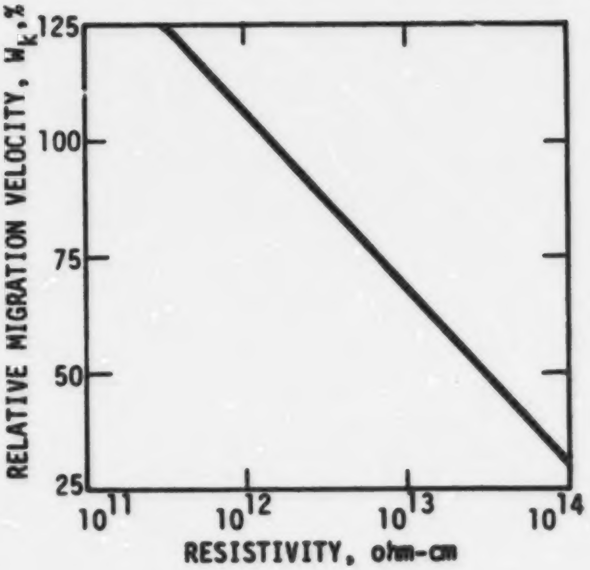

Figure A-20. Precipitator migration velocity vs. resistivity.[7]

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Water conditioning of the excess air by injection and evaporation of water in the cooler can change the ESP operating conditions, for example, from point A in Figure A-21 to point B, along the line A-B. The slope of the line A-B is determined by the proportion between the air cooling effect and the air humidifying effect of the injected water. Any other conditioning line (for example, A1-B1) will therefore have practically the same slope in the diagram as A-B. The length of a conditioning line is directly proportional to the amount of water injected. These assertions, of course, are only true if the water is injected into the cooler in such a way that it evaporates in and cools the excess air, not the clinker.[7]

The information in Figure A-21 indicates that an appropriate control system should be designed to maintain ESP operating conditions in areas with high migration velocities, i.e., outside or close to the ω_3 curve and avoiding the low ω area of dry air around 180°C.

With sets of water injection nozzles arranged above the cool end of the clinker bed and controlled by the cooler exit air temperature, ESP operating conditions can be maintained approximately along the operating control line I-II (Figure A-21). This method will provide satisfactory ESP efficiency and acceptable dust emission levels during varying clinker cooler operation.[7]

STARTUP AND SHUTDOWN PROCEDURES

As noted, periods of process startup and shutdown are critical to ESP operation. The following items are provided as general operating rules of thumb to follow during these periods[11]:

- If hopper or support insulator heater elements are available, these heat sources must be in operation at least 3 hours before startup.
- The combustible level in the gas exiting the kiln should be ascertained before the ESP is electrically energized.
- It is generally preferable to preheat the ESP to as high a temperature as possible before energization of the power supplies. Gas temperatures of 180° to 200°F at the exit of the ESP are recommended. If ESP operation is required before this temperature range is reached, the outlet electrical fields should be energized first at low power settings.

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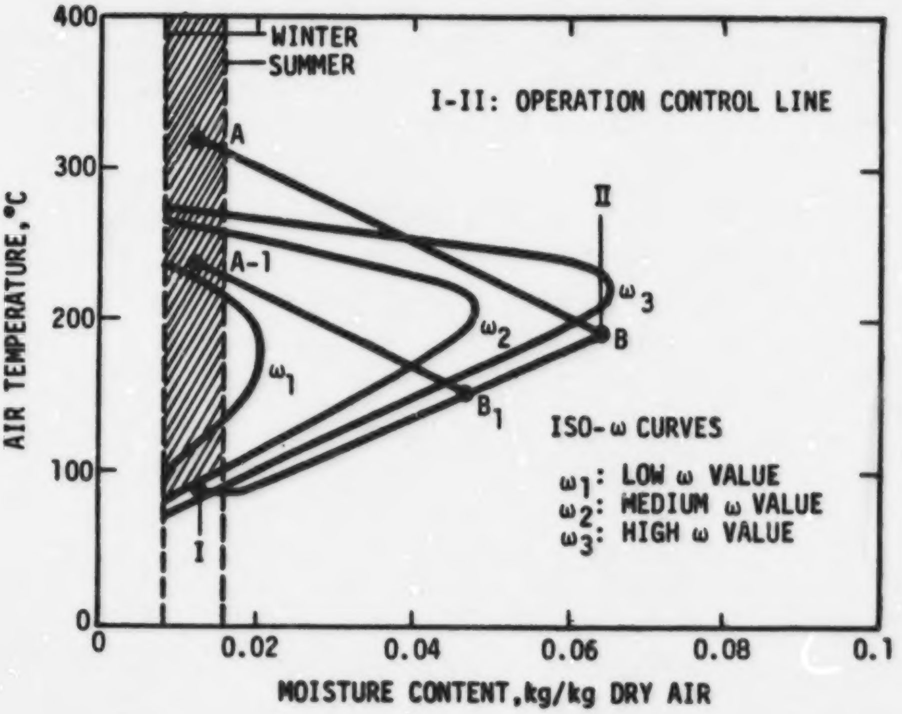

Figure A-21. Relationship between migration velocity ω and air temperature and moisture content including resistivity effect.[7]

- All rapper equipment should be placed in service prior to startup of kiln.
- All hopper evacuation equipment must be in operation before startup of the kiln.
- Upon shutdown of the process, the electrical sections of ESP should be deenergized before the gas temperature falls below 200° to 250°F at the exit of ESP. Shutdowns of the ESP should be initiated in an orderly fashion from the inlet to outlet fields. Rapper operation must be kept at maximum intensity. The time intervals for shutdown of the power supplies should be gauged to minimize the discharge from stack. Each installation may require a different procedure, but the object is to achieve effective cleaning of the electrode surfaces. The operation of the induced draft fan must be considered in the procedure. All conveyors and hopper systems should be kept operable.

Effective operation of an ESP in a cement plant depends on proper design and proper maintenance. Table A-3 presents some of the more common problems associated with ESP operation. As indicated, most malfunctions result from lack of maintenance and attention to the control system.[2]

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TABLE A-3. DETECTION AND SOLUTION OF ESP OPERATING PROBLEMS[2]

Control panel indicators						
Primary voltage, a.c.	Primary current, amps	Secondary current, mA	ESP conditions/ panel indications	ESP control efficiency[a]	Possible problem	Problem solution
350[b]	40[b]	160[b]	Normal operation	Normal		
285	120	500	Gas volume and dust load decreases.	Higher than normal		
400	30	140	Dust load increases.	Usually higher than normal		
350-400	40-150	100-700	In wet processes, temperature increases but resistivity is constant. In dry processes, temperature and resistivity increase.	Higher than normal for wet processes, but lower than normal for dry processes		
240	40	200	Gas temperature decreases.	Normal unless below dewpoint		Raise process temperature.
240	170	400	Arcing between electrodes	Less than normal	Higher hopper level Dust bridging in in hopper	Increase dust removal rate. Use hopper vibrator.
400	40	160	Added primary voltage is required to maintain constant current; spark rate increases.	Less than normal	Failure of discharge electrode rapper to remove dust from electrodes.	Increase rapping intensity. Repair rapper system.
240	40[b]	160	Less primary voltage is required to maintain constant current. Spark rate increases.	Less than normal	Failure of rapper on collection plate to remove dust buildup	Increase rapping intensity. Repair rapper system.

TABLE A-3 (continued)

Control panel indicators						
Primary voltage, a.c.	Primary current, amps	Secondary current, mA	ESP conditions/ panel indications	ESP control efficiency[a]	Possible problem	Problem solution
0-350	0-40	0-160	Violent fluctuation of indicators; high arcing noise	Zero to normal	Broken electrode with top part swinging back and forth	Isolate section until electrode can be replaced.
0	120	0	No current flow to precipitator	Zero	Electrical short circuit of transformer-rectifier (T-R) set, or wire grounded out	Repair or replace T-R set.
			High spark rate	Less than normal	Air leakage through inlet ductwork Air leakage through inspection hatches	Seal points of of leakage. Seal hatch doors.
			Corrosion (internal inspection)	No immediate effect	Inlet gas at temperatures less than dewpoint Problems encountered during startup and shutdown of kiln	Maintain gas temperature above dewpoint. Use insulation and hopper heaters.

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[a] The effects of ESP problems can only be stated on a qualitative basis.

[b] Multiple-field ESP: primary voltage decreases in moving from inlet to outlet fields, and primary current increases in moving from inlet to outlet fields.

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APPENDIX B
ESP APPLICATIONS IN KRAFT PULP INDUSTRY

INTRODUCTION

Electrostatic precipitators servicing kraft recovery boilers are designed to control particulate (salt cake) emissions to meet allowable regulatory limits. The success of maintaining high collection efficiency depends on how well an ESP was designed for the expected operation of the associated recovery boiler and its various influences (e.g., nature of the black liquor to be burned) and on operation of the recovery boiler in accordance with the design parameters of the ESP(s).

Numerous factors (e.g., gas volume, particulate loading, corrosion) affect the performance of ESP's that service Kraft recovery boilers. Effective O&M practices oftentimes can keep these factors within acceptable limits and enable the recovery boilers to operate in compliance with particulate emissions regulations on a long-term, continuous basis. The primary intent of this Appendix section is to describe the boiler and ESP related factors, one by one, and to list and explain effective O&M practices applicable to each factor. Descriptions of the boiler-related factors and O&M practices are discussed prior to the ESP-related factors and their O&M practices. A brief description of recovery boiler operation is presented first.

KRAFT RECOVERY BOILER OPERATION

The kraft recovery boiler or furnace is an indirect water-walled steam generator used to produce steam and to recover inorganic chemicals from spent cooking liquors. (A schematic of the kraft process is shown in Figure B-1.) The boiler consists of a large vertical combustion chamber lined with water tubes. The heat exchanger section typically consists of a low-pressure

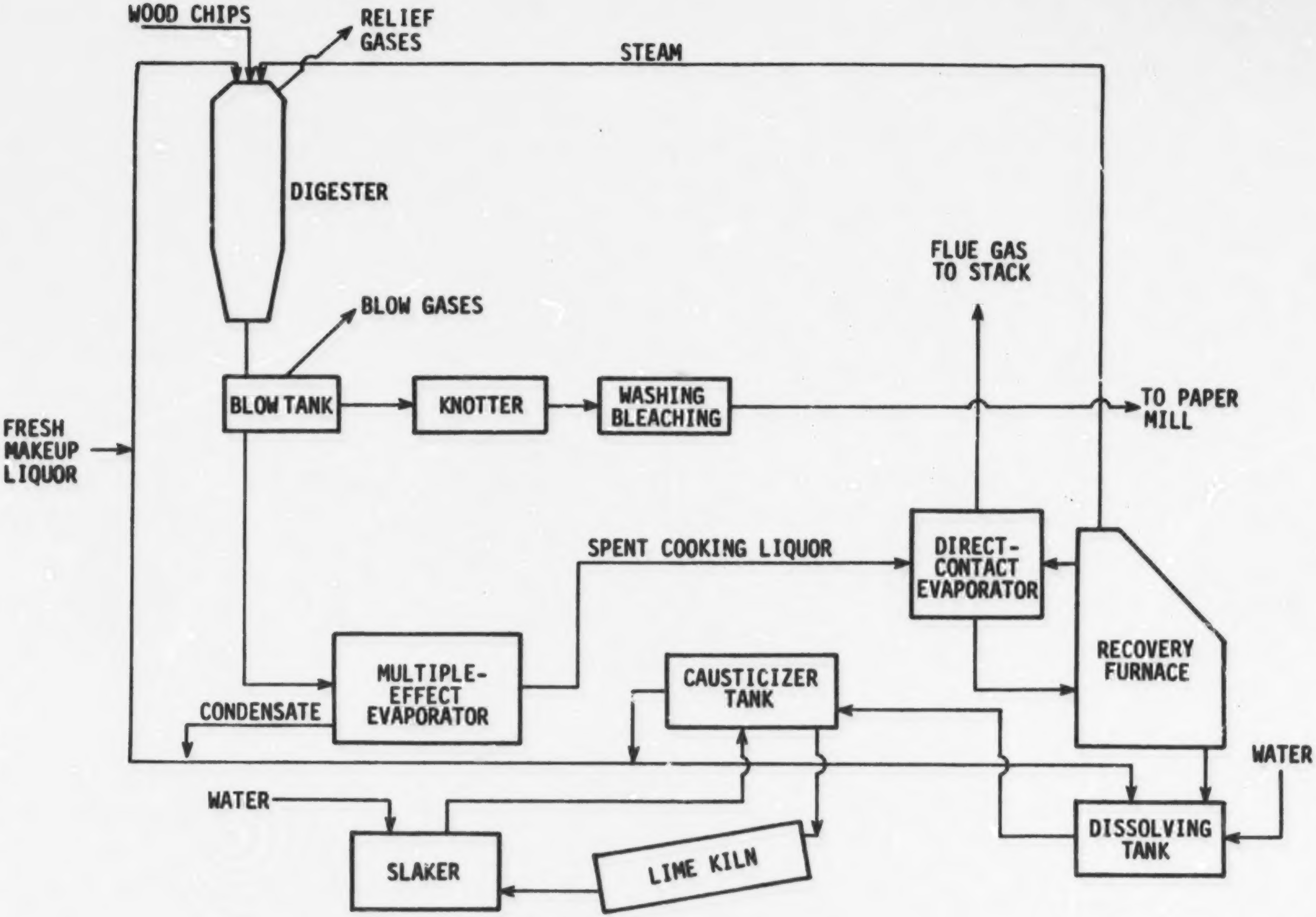

Figure B-1. Schematic of kraft process.[1]

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boiler, superheater, and economizer. Figure B-2 shows a cross section of a modern Babcock and Wilcox (B&W) boiler.[2] The fuel used in the boiler is spent concentrated cooking liquor (black liquor). The liquor in the burners has a solids content of between 60 and 70 percent (depending on wood species and yield) and is made up of organic and inorganic fractions.[3,4] The organic fraction contains lignin derivatives, carbohydrates, soap, and waxes.[5,6] The inorganic portion consists primarily of sodium sulfate.

Black liquor is sprayed into the furnace at an elevated level in the combustion chamber through a number of steam or mechanical atomizing nozzles. The suspended liquor is burned as it falls through the combustion zone. The following are the major steps in the combustion process:[7]

- The liquor is dehydrated to form a char.
- The char is burned in a bed at the bottom of the furnace.
- The ash (inorganic portion) remaining after combustion of the char is exposed to active reducing conditions to convert sodium sulfate and other sodium-sulfur-oxygen compounds to sodium sulfide.
- The organic materials in the upper section of the furnace are oxidized to complete combustion.

Reduced inorganic material (smelt), which consists of a mixture of sodium sulfide and sodium carbonate, is continuously drained from the furnace. The ratio of sodium sulfide to sodium carbonate depends on the temperature and the ratio of sulfur to sodium in the fired liquor.

Combustion of the char begins on the hearth of the furnace. Air for combustion is supplied through air ports located in the furnace walls. The primary air supply is used to initiate char combustion. The primary air supply, which is introduced in the lower portion of the char, is kept to a minimum to maintain the necessary reducing conditions to convert the ash to sodium sulfide. The secondary air supply is located at a higher level in the furnace to create the oxidizing condition necessary to control the char bed height. A tertiary air supply may be used to complete combustion in the upper levels of the furnace and thereby eliminate reduced sulfur compounds. As the char bed is burned, the inorganic ash is liquified and drained to the furnace hearth, where it is reduced.

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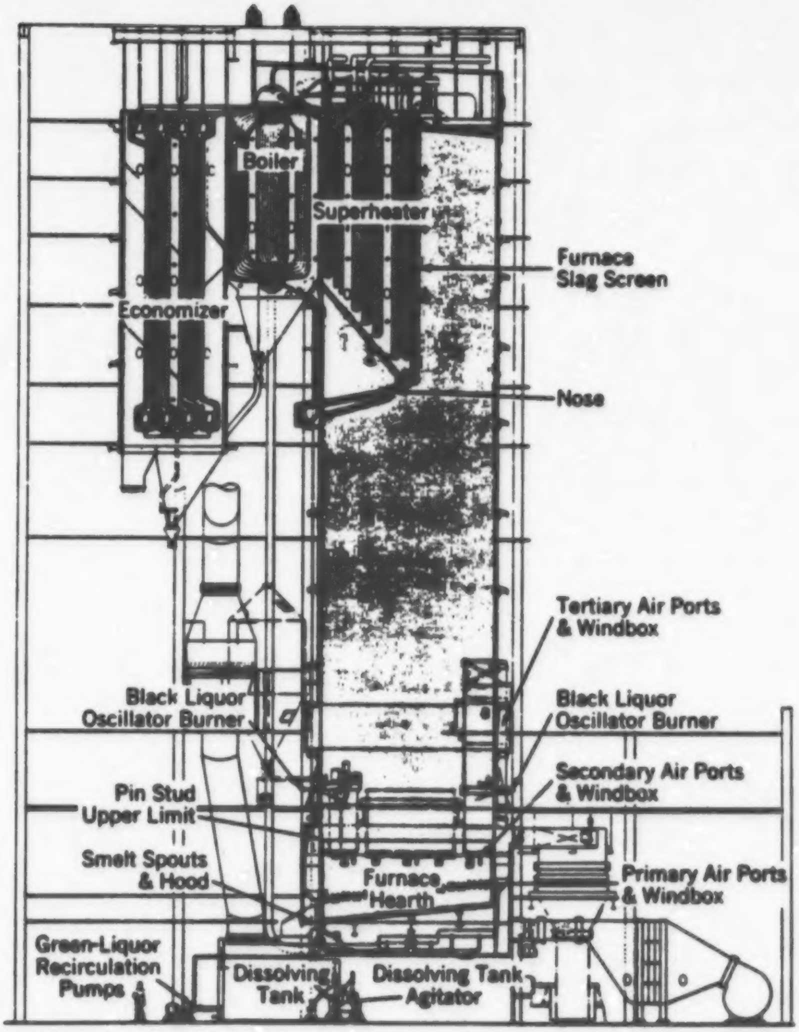

Boiler
Superheater
Furnace Slag Screen
Economizer
Nose
Tertiary Air Ports & Windbox
Black Liquor Oscillator Burner
Black Liquor Oscillator Burner
Secondary Air Ports & Windbox
Pin Stud Upper Limit
Smelt Spouts & Hood
Furnace Hearth
Primary Air Ports & Windbox
Green-Liquor Recirculation Pumps
Dissolving Tank
Dissolving Tank Agitator

Figure B-2. Cross section of B&W recovery boiler.[2,7]

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Combustion gases produced by the burning of the liquor are passed through the heat exchanger section of the boiler before being exhausted to a particulate control device. The gases are cooled to about 800°F in the boiler tube bank before passing into the economizer. Temperature of the gas leaving the economizer, which is about 750°F, is reduced in either indirect-contact or direct-contact evaporators.

There are three types of direct contact evaporators: cyclone, venturi, and cascade. Cyclone evaporators concentrate the black liquor by placing it in contact with the high-temperature gas stream by using the wetted wall of the cyclone.[4] The cyclone removes approximately 50 percent of the uncontrolled particulate from the gas stream. A venturi evaporator concentrates black liquor by placing the flue gas in contact with liquor through the generation of liquor droplets. The droplets are generated through the shearing action of the gas stream as it passes a weir into which the liquor is being pumped. Venturi evaporators remove approximately 85 percent of the uncontrolled particulate emissions generated by the furnace when operated at 4 to 5 in. H_2O pressure drop. In the cascade evaporator, a thin film of liquor coats several tubes rotated through the flue gas stream. This type of evaporator will generally increase the black liquor solids content from 48 to 65 percent. The rate of evaporation is related to the flue gas temperature and the cascade rotation rate. The evaporator can be operated beyond design rates without substantial process upsets, and can remove up to 50 percent of uncontrolled particulate emissions from the furnace.

There are three types of indirect-contact evaporators. In general, these evaporators evaporate the liquor by use of a noncontact tube and shell design. Because the black liquor in a noncontact evaporator design does not come in contact with the flue gas, stripping of TRS compounds is prevented. Evaporated water is condensed by using a tail gas condenser. Noncondensable gases are directed to lime kilns or into the furnace primary air system for incineration.

The high temperatures in the furnace char zone result in a partial vaporization of sodium and sulfur from the smelt. The fume is removed from the furnace with the combustion gases and condenses to a fine particulate consisting of sodium sulfate (Na_2SO_4) and sodium carbonate (Na_2CO_3).

Modern recovery boilers are sized for two process conditions: 1) the heat input to the furnace, and 2) the weight of the chemicals to be recovered. Both of these conditions affect the heat release rate as a function of furnace volume (Btu/ft^3) and furnace cross section or hearth area (Btu/ft^2). Typical design values are on the order of 9800 Btu/ft^3 (furnace volume) and 900,000 Btu/ft^2 (hearth area).[8] The exact dimensions of the furnace depend on the elemental composition, solids content, heat value, sulfidity, and chloride content of the black liquor. Deviations of 10 percent or greater in design variables should be investigated to ensure maximum efficiency.[8] The manufacturers generally consider the boiler to be overloaded when the firing rate (Btu/h) exceeds 120 percent of the rated value. Operation outside of design values can cause tube fouling and reduced smelt recovery, which can increase emission rates and reduce thermal efficiency.

Major Boiler-Related Factors and O&M Practices that Affect Uncontrolled Particulate Matter

The rate of uncontrolled particulate matter from a recovery boiler and the resulting loading to the ESP(s) depends on a number of interrelated boiler operating variables. Several of the major ones are listed here and then separately discussed:[9-12]

- Firing rate [pounds of black liquor solids (BLS) per hour]
- Black liquor heating value (Btu/pounds BLS)
- Black liquor concentrations (percent solids)
- Total combustion air (excess air)
- Primary air rate (percent of total air)
- Secondary air rate (percent of total air)
- Char bed temperature

In addition to affecting the uncontrolled emission rates (as generally shown in Table B-1), these variables can also reduce ESP performance. The following discussion addresses both of these effects.

Reductions in TRS and SO_2 emissions from kraft furnaces result primarily from the optimization of process variables that cause sulfurous gases to

TABLE B-1. SUMMARY OF THE EFFECTS OF RECOVERY BOILER PARAMETERS ON PARTICULATE EMISSION RATES

Parameter	Change	Effect on particulate emission rate
Firing rate	Increase	Increase
Primary air	Increase	Increase
Excess air	Increase	Increase
Smelt bed temperature	Increase	Increase
Flue gas oxygen [a]	Increase	Increase
Primary air temperature	Decrease	Decrease
Black liquor sulfidity	Increase	None

[a] If increase in oxygen is a result of an increase in primary air volume.

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become chemically combined with sodium to form a particulate emission. Operation of the boiler under these process conditions can also increase uncontrolled particulate emissions in the form of sodium sulfate.

Firing Rate--

The firing rate of a kraft recovery boiler is measured in pounds of black liquor solids per unit of time (either pounds BLS/24 hours or pounds BLS/hour). Given a specific heat value of the black liquor solids, percent solids in the liquor, and elemental composition of the liquor, one can define the flue gas volume produced and the boiler heat input. The firing rate of a recovery furnace is often increased to increase pulp production rates. This usually requires more gallons per minute of the fired liquor. The firing rate is limited by the pumping capacity of the system, which is based on the liquor temperature and viscosity.

Table B-2 presents the various operating conditions of a recently inspected recovery boiler with a firing rate of about 56,000 pounds BLS/hour. This Combustion Engineering boiler has a design process rate of 500 tons of air-dried pulp per day or 55,400 pounds BLS/hour.

The importance of the boiler firing rate with respect to performance of the accompanying ESP(s) is that increased firing rates increase both the resultant flue gas volume and the uncontrolled emission rate. As more black liquor solids are sprayed into the furnace, more air is required to support proper combustion and more emissions per unit of time are generated. Generally, the uncontrolled emission rate of a typical, indirect-contact, recovery boiler is 8 gr/dscf. Actual rates, of course, are boiler-specific.

A higher-than-design flue gas volume increases the vertical gas velocity through the furnace combustion zone and results in more particulate emissions due to the entrainment of black liquor droplets and char particles. This situation not only increases the particulate emission rate, but also increases the particulate concentration and changes the nature of the particulate, both of which can adversely affect the ESP(s).

Flue gas temperatures also increase as the flue gas velocity increases (because of increased air volume). This occurs when the increased velocity

TABLE B-2. OPERATING CONDITIONS OF RECENTLY INSPECTED RECOVERY BOILER

Steam flow	165,000 lb/h
Steam pressure	600 psig
Steam temperature	700°F
Feedwater pressure	880 psig
Feedwater temperature	330°F
Primary air flow	50,000 lb/h
Primary air temperature	288°F
Black liquor temperature	252°F
Black liquor flow	117 gal/min
Black liquor solids content	66%
Black liquor nozzle size	No. 5
Number of liquor guns	6
Black liquor solids firing rate	56,062 lb/h
Boiler heat input	347.6 x 10^6 Btu/h
Boiler output (steam)	186.6 x 10^6 Btu/h
Boiler efficiency (calculated)	53.7%

decreases the efficiency of the steam tube heat transfer. The effect of temperature on an ESP was described in the body of the manual.

Because the boiler firing rate can affect flue gas volume, flue gas temperature, and the rate and concentration of particulate emissions (all which can greatly affect ESP performance), this operating parameter should be monitored carefully. Some effective O&M practices in this regard are as follows:

° The importance of recovery boiler firing rate on ESP performance should be recognized and communicated to personnel responsible for boiler operation and ESP operation on all shifts.

° Based on previous stack tests (such as the ESP performance test), the inlet and outlet grain loading air volume and temperature at the ESP should be evaluated against the boiler firing rate. Established baseline conditions should be used for comparison with normally monitored and recorded boiler data.

° The boiler operator and plant management should be kept aware of the "acceptable" firing rate range. As additional stack test data or other pertinent data are collected, the acceptable range should be re-evaluated and updated as necessary.

° Boiler personnel need to keep the environmental engineer appraised of boiler changes that could affect flue gas conditions (e.g., installation of new liquor guns; change in fuel oil characteristics, if fuel oil is used as a supplemental fuel).

° The environmental engineer should be familiar with the "F-factor," which is the measured flue gas volume (dry standard cubic feet per minute corrected to 0 percent flue gas oxygen) divided by the boiler black liquor solids firing rate (pounds BLS/minute). The value of the F-factor varies from mill to mill because of the variation in species, pulp yield, makeup chemicals, and evaporator operation. This value, however, is reasonably constant for a specific mill.

Knowledge of the F-factor allows periodic calculation of flue gas volumes to ensure that the boiler is not exceeding design values. For a more accurate calculation of velocities in the combustion chamber and the total flue gas volumes, the F-factor must be corrected for water evaporated from the fired liquor, water of combustion, temperature, excess air, and miscellaneous additions such as steam from soot blowing.

- When the boiler firing rate, flue gas volume and temperature, and/or particulate levels are determined to be outside determined acceptable ranges, the appropriate personnel must be consulted. For example, a meeting of the environmental engineer, boiler operator, and maintenance person may be in order. If the operating conditions could adversely affect the ESP, the environmental engineer needs to know what is acceptable and how to resolve an unacceptable situation.

Black Liquor Heating Value and Solids Content--

Based on computer models of recovery boiler operations, particulate emissions increase sharply with increases in the heat value; they increase less, but significantly, with higher solids content in the black liquor (Figures B-3 and B-4). These changes are primarily the result of changes in the heat production rate of the char bed.[12]

Because the heat value and solids content of black liquor are dependent on several process variables in the pulping process (e.g., digesters, evaporators, wood species, and harvest conditions), day-to-day firing conditions and liquor properties may vary significantly. This variability makes these factors difficult to control. It is important that the environmental engineer know the allowable variation of the inlet grain loading the ESP is designed to handle.

Combustion Air--

For proper and adequate combustion in a recovery furnace, the total amount of combustion air usually must be between 110 and 125 percent of the calculated theoretical (stoichiometric) air requirement. Incomplete combustion normally occurs below this range, which is unacceptable for the operation of a recovery boiler. Excess air (i.e., that which exceeds the theoretical amount) is monitored and controlled in the boiler control room so that proper combustion can be maintained.

Because the boiler operators' primary interest is in maintaining complete combustion, it has been noted during some inspections that too much excess air has been allowed. This can lead to particulate control problems, and even to boiler problems that the boiler operator may not be aware of. When the amount of excess air exceeds 125 percent (5 percent O_2 in flue

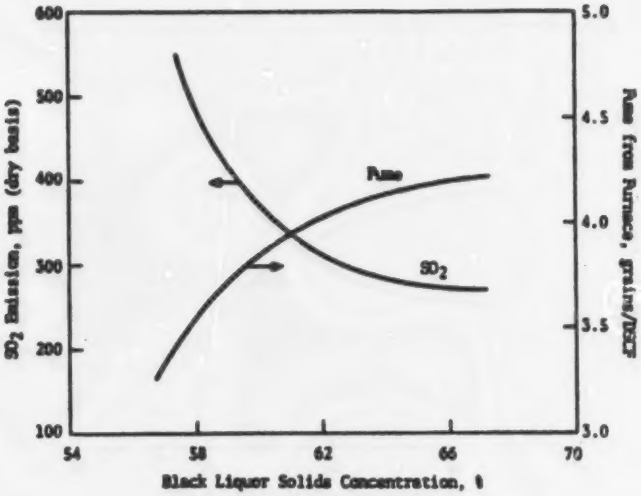


Figure B-3. Effect of black liquor solids concentration on uncontrolled particulate emissions.[12]

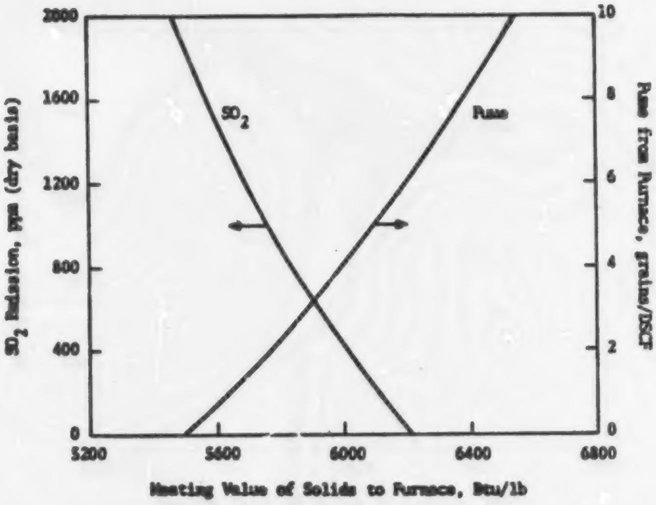


Figure B-4. Effect of black liquor heating value on uncontrolled particulate emissions.[12]

gas), formulation of SO_3 increases in the boiler.[12,13]. The SO_3 that is absorbed in the particulate at low temperatures makes it sticky, and this sticky particulate fouls heating surfaces in the economizer and reduces heat transfer rates. The deposits may cause in a high draft across the economizer. The particulate (salt cake) can also cause severe operating problems when collected on the plates of the ESP.[13] Soot blowers cannot effectively remove the sticky salt cake from the boilers, and normal rapping intensity cannot remove it from the ESP plates. A method to determine what level of SO_3 will cause sticky particulate is to prepare a 4 percent salt cake solution in water and if the pH is <9.5, then the operator can expect to see sticky particulate buildup.

Particulate buildup on the plates causes low collection efficiency because it reduces the power input to the unit. The effect is more prevalent when flue gas temperatures fall below 300°F and a combination of high boiler excess air and ambient air in leakage occurs.[13]

Combustion air consists of primary air and secondary air, and maintaining of the proper percentages of the two is important for good boiler operation and particulate emission control. Primary air is required to provide combustion under reducing conditions and to maintain the temperature in the char bed to prevent a condition called "blackout." The proper amount of air is a compromise between maintaining sufficient combustion and reducing abnormally high vertical velocities in the furnace. High velocity results in an accumulation of deposits on the heating surface of the boiler (after cooling of the gas stream and condensation of fume), and this accumulation causes increased particulate emissions.

A high rate of primary air (particularly at high velocities) increases the release of sodium and sulfur from the char bed because of the greater diffusion of the vapor from the bed.[11] The higher air volume also increases the combustion rate of the char, which increases the bed temperature. Particulate emissions increase sharply when the amount of primary air exceeds 45 percent of the total air volume.[12]

Prolonged operation at low primary air volumes can increase the char bed height, which must be reduced by an increase in bed temperature. The most common method of reducing the bed height is to increase the primary and secondary air volumes, which alters the smelt ratio as oxidation and temperature conditions are changed.

The secondary air should make up at least 40 percent of the total air (maximum of 65 percent of the theoretical air).[2] In boilers with a high char bed, the secondary air has two purposes: 1) the primary purpose is to complete combustion of CO gas released from the char bed as it moves up the furnace walls; and 2) the secondary purpose is to provide air in the center of the furnace to burn the char bed.

The total air volume (secondary plus primary) must be large enough to produce complete combustion, but it also must be limited to a level that will reduce the vertical velocity in the furnace and total flue gas volume.

Thus, good control of combustion air is obviously important to proper boiler operation; however, in this report, it is even more important for the control of the loading and chemical consistency of particulate matter reaching the electrostatic precipitator(s). In summary, improper control of combustion air can cause "blackout" (incomplete combustion of black liquor); sharp increases in particulate emissions (e.g., that caused by primary air exceeding 45 percent of total air); and formation of sticky particulate (excess air greater than 125 percent, SO_3 absorption with particulate).

Improper control of combustion air can also cause increases in char bed temperature (the adverse effects of this are discussed later) and high flue gas velocity (the adverse effect of which were described under "firing rate".

Effective O&M practices for maintaining proper control of combustion air include the following:

- The boiler operator and environmental engineer must communicate frequently and recognize each other's concern for proper control of combustion air. Fortunately, good control of this parameter is a shared concern.
- The environmental engineer should try to develop relationships between the percent excess air and primary air in the recovery boiler and the following:
    - Particulate loading to the ESP (This can be done during performance tests. If tests have already been performed, test data and boiler operating logs can be located and evaluated.)

  - Observance of visible emissions from the ESP(s). (If this occurs, different ESP and boiler parameters should be checked including combustion air levels.)

  - Air volume to the ESP. Increases in air volume also can be due to other factors, such as in- leakage. Excess air volume data are available in the boiler control room, and points of inleakage can be determined by measuring the oxygen content with portable equipment at strategic duct locations.

  - Flue gas temperature to the ESP.

- The empirically determined relationships can be very useful in the detection of ESP operating problems. Graphical representation of the relationships are easy to "read" and to describe to other personnel (e.g., boiler operators, maintenance personnel, management).

- The environmental engineer must be familiar with the boiler operation and understand why the boiler operator may vary the excess air to the furnace. He/she should know how to read the instrumentation so that he/she can periodically check the readings.

- The environmental engineer should review ESP maintenance logs for problems caused by sticky particulate. Maintenance personnel should be consulted to get their opinions of the problems. The boiler operators and operating logs (on those maintenance days) should be consulted to see if any changes in boiler operation occurred. There is usually a link between operating, maintenance, and environmental problems. The environmental engineer can try to determine these links and then get back with the operating and maintenance personnel. Such personal associations and interest should encourage working together to optimize operating conditions.

Char Bed Temperature--

The amount and nature of particulate emissions vary considerably, depending on the char or smelt bed temperature. As shown in Figure B-5, this temperature is greatly affected by the percentage of combustion air. The smelt bed temperature is also directly influenced by the primary air temperature. Although a figure is not available to show the effect of char bed temperature on uncontrolled particulate emissions, Figure B-6 shows the effect of primary air temperature of the uncontrolled particulate grain loading. The recovery boiler firing rate, which is interconnected with the above factors, also affects the char bed and resultant particulate emissions.

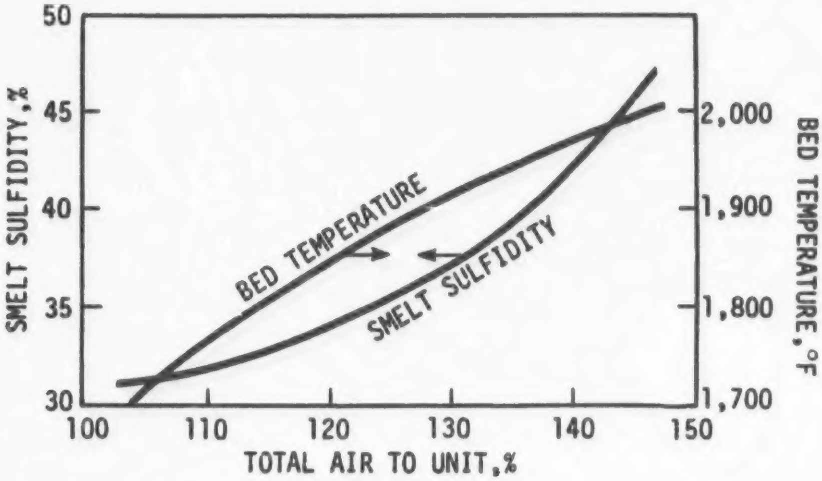


Figure B-5a. Bed temperature as a function of total air.[12]

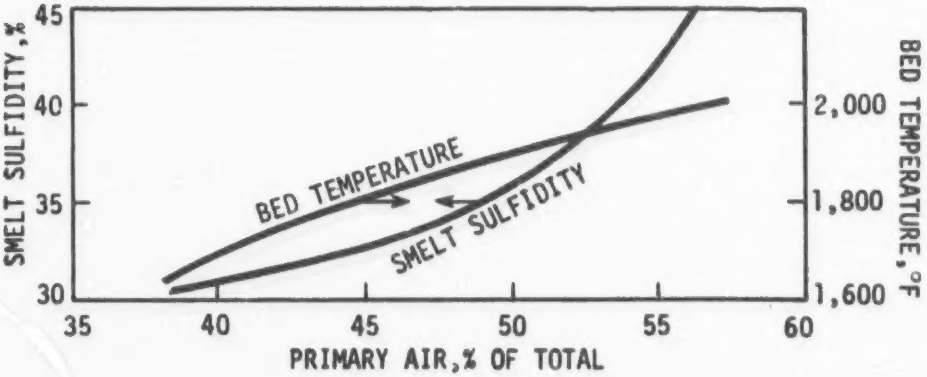
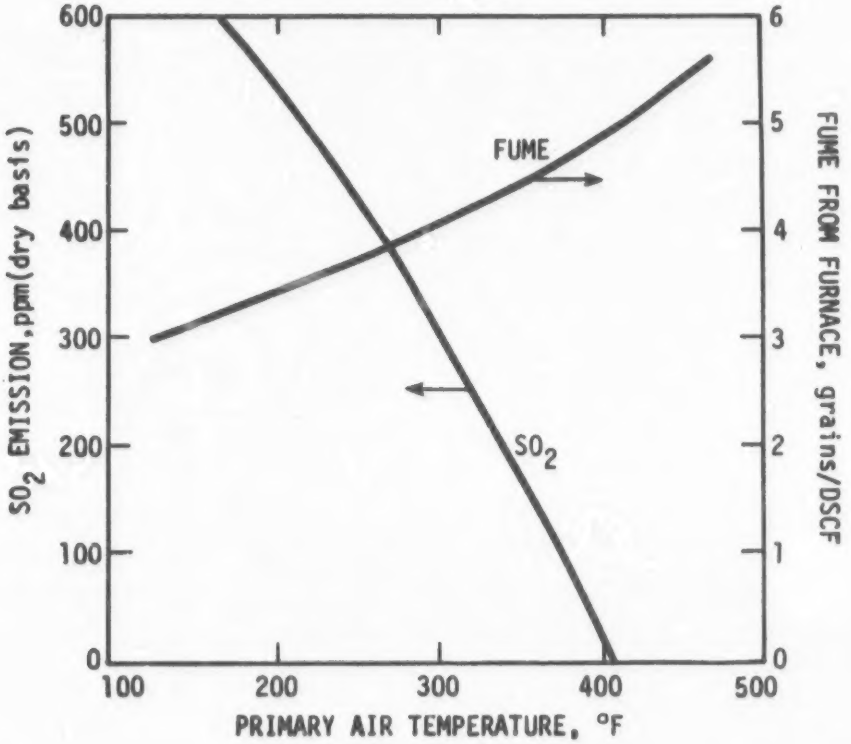


Figure B-5b. Char bed temperature vs. percentages of primary and total combustion air.[12]



Figur -6. Effect of priamry air temperature on particulate emissions.[12]

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A qualitative discussion of the mechanisms by which particulate emissions are increased is presented here. Dehydrated liquor (char) on the furnace hearth is burned at a high temperature to allow the inert portion of the liquor to melt and drain from the hearth. A mixture of sodium sulfide and sodium carbonate must be maintained under reducing conditions to prevent oxidation to sodium oxides.

Under normal operating conditions, elemental sodium is vaporized and reacts to form Na_2O. The rate of evaporation depends on the char bed temperature and the diffusion conditions in the smelt zone. As the sodium evaporates from the bed, it reacts with oxygen in the primary air zone to form Na_2O. The Na_2O reacts with CO_2 to form Na_2CO_3.[14]

The char bed temperature also determines the rate of sulfur released to the flue gas. Sulfur is commonly present in the flue gases as S, H_2S, SO_2, or SO_3. The higher temperatures favor the formation of SO_2 and SO_3. Sulfur in the form of S and H_2S reacts with excess oxygen in the oxidizing zones of the furnace to form SO_2 and SO_3. The Na_2CO_3 reacts with the SO_2 to form Na_2SO_3, which is later oxidized to Na_2SO_4. Typically, the Na_2SO_4 deposits on the heat exchanger surfaces (screen tubes, superheater, and boiler tubes) and must be removed through continuous sootblowing. Because these deposits reduce the heat transfer and the overall efficiency of the boiler, the tendency is to overfire the boiler to achieve the required steam flow. This increases both the gas temperature entering the ESP and the superficial velocity.

The factors that influence the smelt bed (i.e., combustion air and firing rate) have already been discussed. The O&M practices described for those factors also apply here and therefore are not repeated. As a reminder, the environmental engineer and the boiler operator should know basically what takes place in the boiler. The boiler operator should at least be aware of boiler operating factors that can affect the performance of the downstream ESP(s). If the boiler has to be operated in a mode where the resultant emissions may adversely impact the ESP(s) or their performance, both the environmental and maintenance department should be notified. Only then can alternatives to these modes of operation be discussed.

Recovery Boiler ESP's

The theory, operation, and basic physical layout of ESP's (as described in Section 2 of the manual) are essentially the same as those for ESP's used on kraft mill recovery boilers. A few items that relate only to kraft recovery boiler ESP's are discussed here.

The control efficiency of kraft recovery boiler ESP's is determined by the initial design of the unit and operating characteristics of the recovery boilers. The older direct-contact kraft process recovery boiler produces salt cake that is a good electrical conductor (low resistivity), and the high gas moisture and acid vapor improve the surface conductivity of the dust. The newer indirect-contact (low-odor) process produces salt cake with smaller particle size distribution and higher dust loading which requires a larger ESP than the direct-contact process. Figure B-7 shows the relationship between the efficiency and the design specific collection area (SCA) on modern recovery boiler ESP's. Figure B-8 shows the design superficial velocity vs. year of installation for 20 randomly selected ESP's servicing recovery boilers.

Two methods are used to support the discharge electrode in recovery boiler ESP's. In the first method, referred to as the weighted-wire design, each electrode is individually supported and tensioned between the plates. In the second method, referred to as a rigid-frame design, the electrode is attached to a rigid frame between the plates. A modification of the second design is a rigid-pipe electrode system, in which the corona is generated on the tip of spikes attached to a vertical pipe.

Collected particulate matter can be removed from the ESP by three different methods. In the first method, referred to as a wet-bottom ESP (Figure B-9), the salt cake is allowed to fall into an agitated pool of black liquor in the bottom of the ESP. In the second method, referred to as a dry- or drag-bottom ESP, the salt cake is allowed to fall onto the flat bottom of the ESP shell, where a drag chain physically moves the material to a discharge screw (Figure B-10).[16] The third method of dust removal consists of a pyramid-shaped hopper with rotary air locks and slide-gate discharges. This design is not often used for recovery boiler ESP's because of hopper plugging problems.

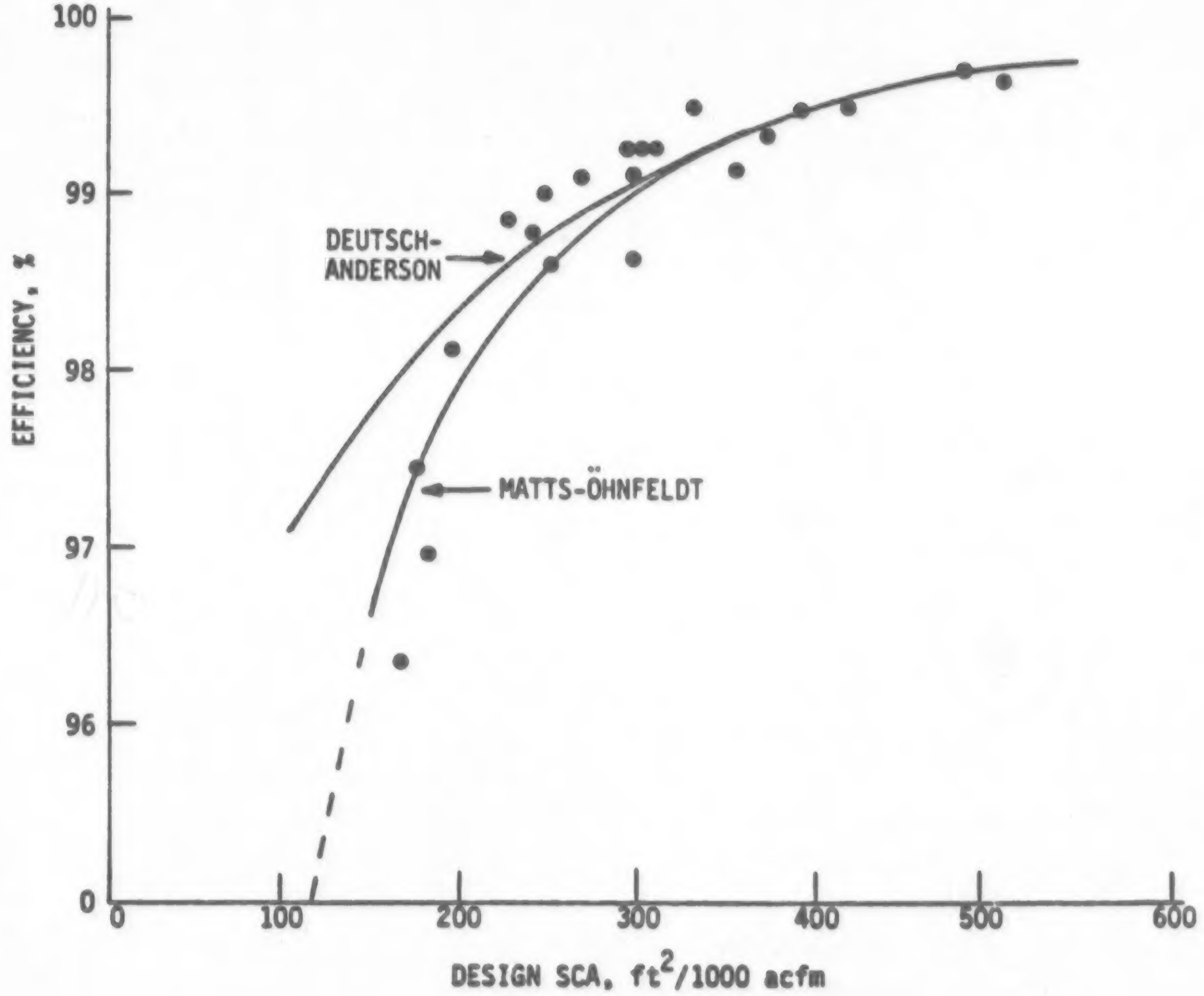

Figure B-7. Design SCA and efficiency of 20 recovery boiler ESP's.[15]

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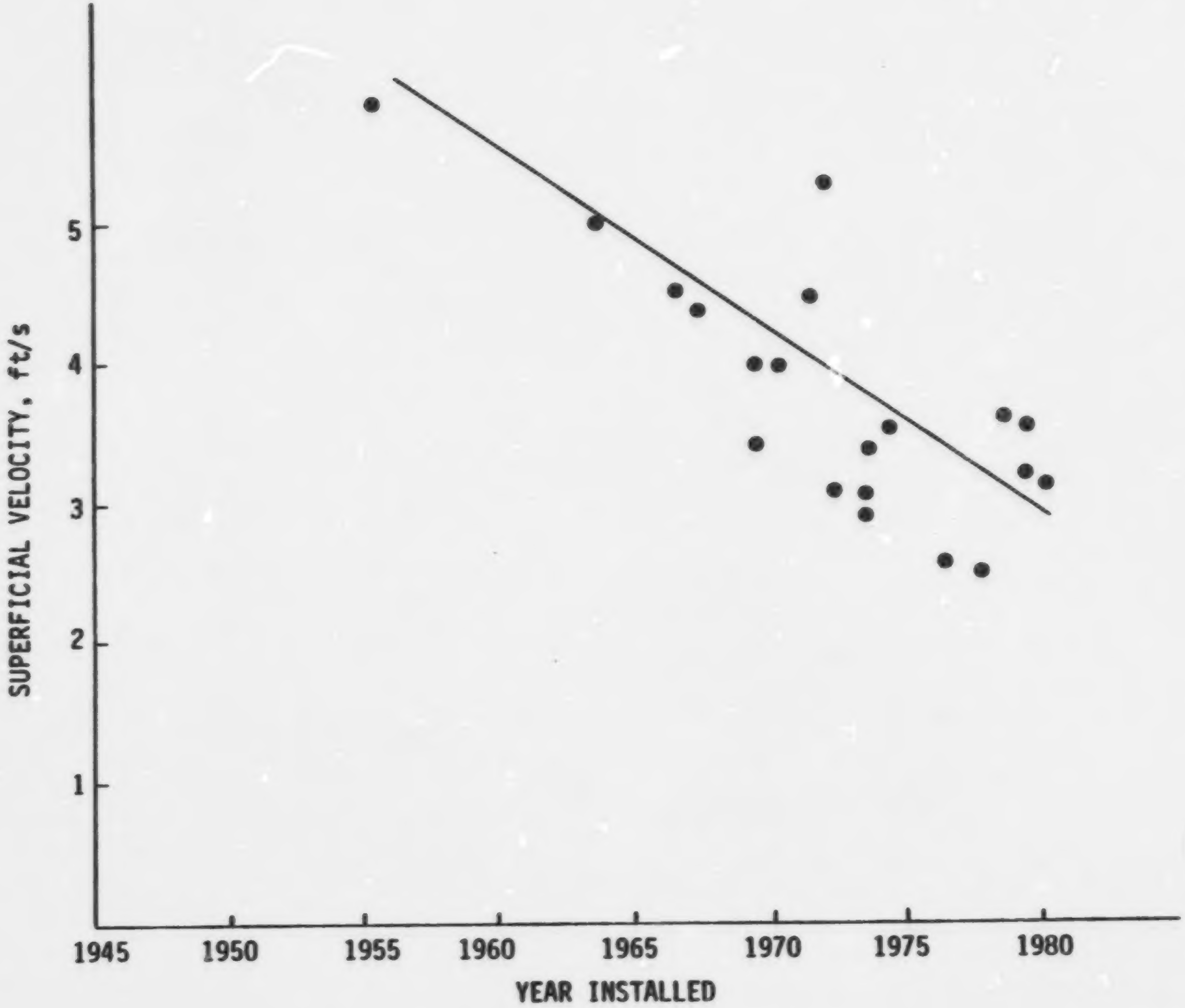


Figure B-8. Superficial velocity versus year installed.[15]

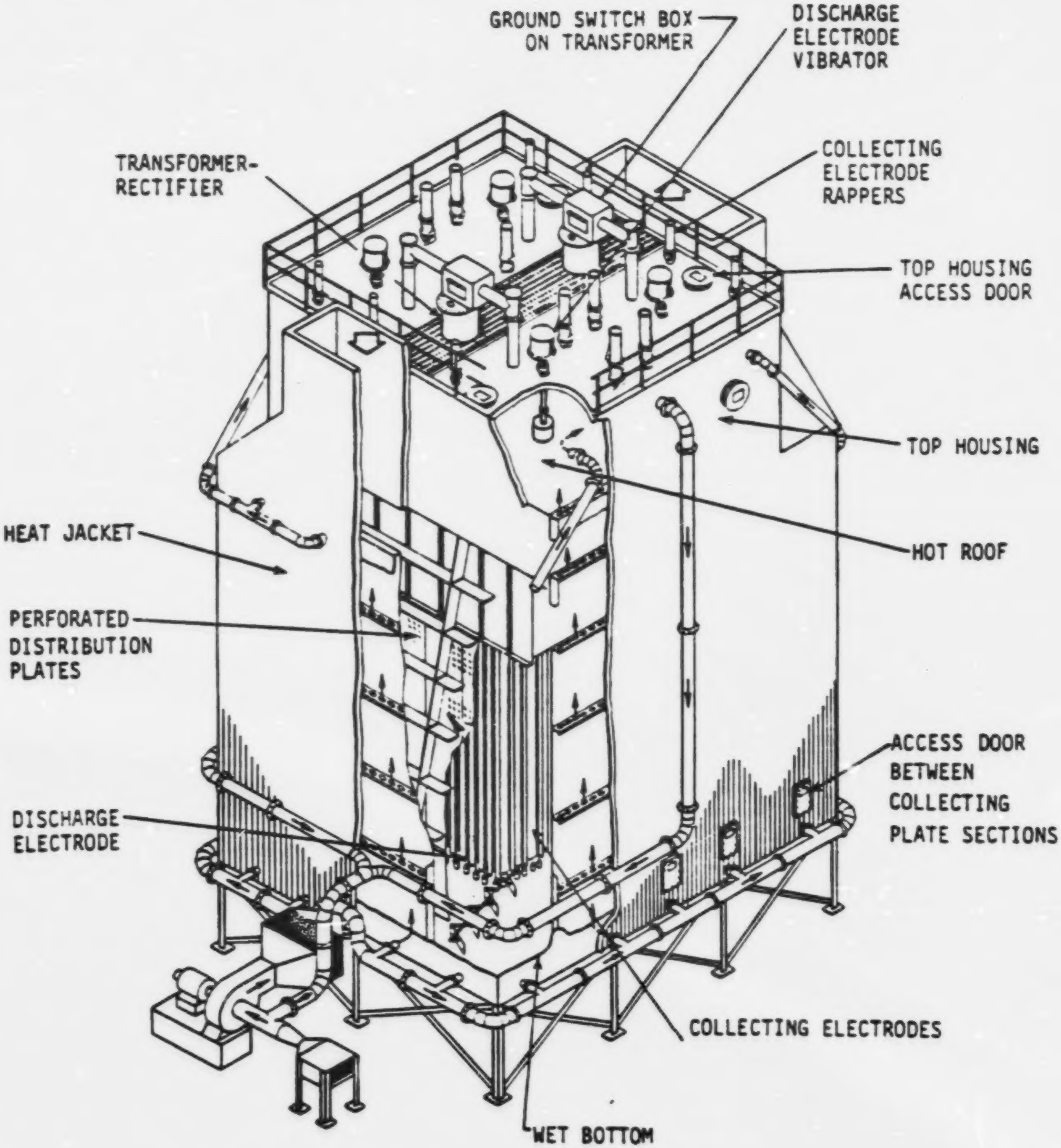

GROUND SWITCH BOX ON TRANSFORMER
DISCHARGE ELECTRODE VIBRATOR
TRANSFORMER-RECTIFIER
COLLECTING ELECTRODE RAPPERS
TOP HOUSING ACCESS DOOR
TOP HOUSING
HEAT JACKET
HOT ROOF
PERFORATED DISTRIBUTION PLATES
ACCESS DOOR BETWEEN COLLECTING PLATE SECTIONS
DISCHARGE ELECTRODE
COLLECTING ELECTRODES
WET BOTTOM

Figure B-9. Typical wet-bottom ESP with heat jacket.[19]
(Courtesy of Research Cottrell, Inc.)

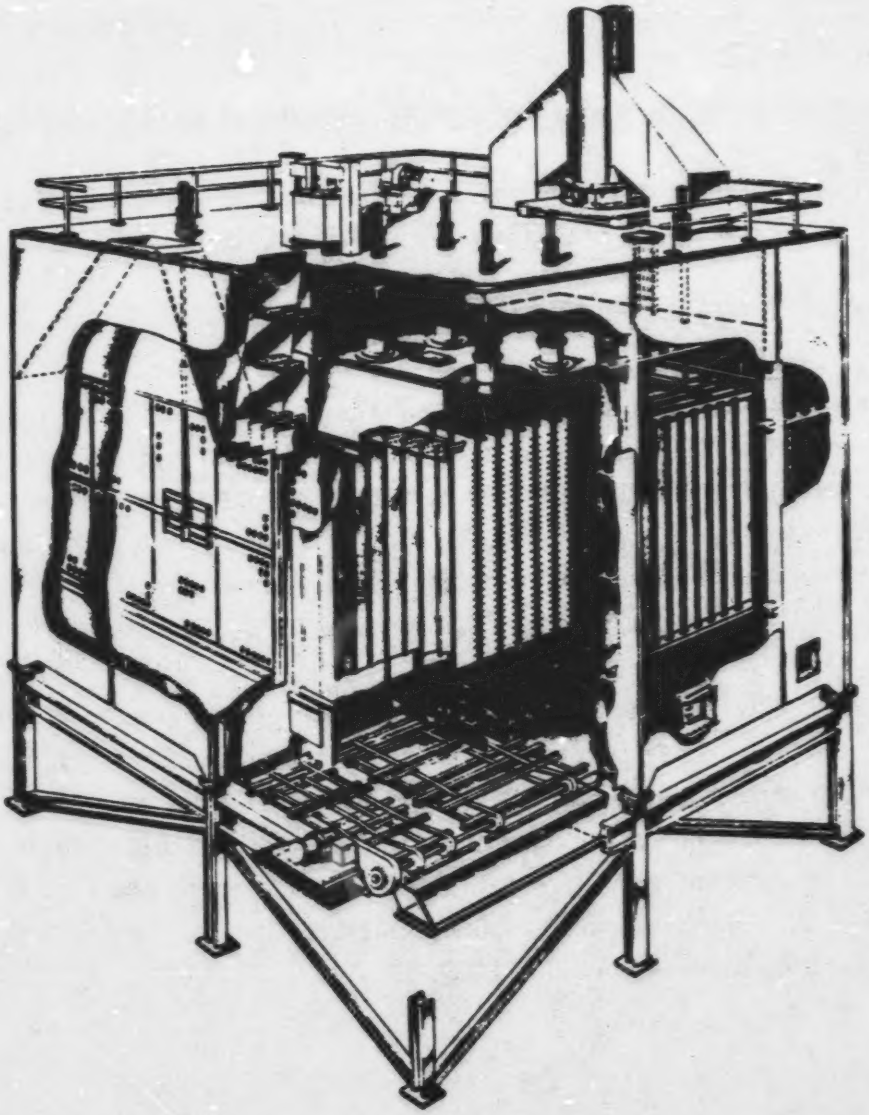


Figure B-10. Typical weighted-wire ESP with drag bottom.[16]
(Courtesy of Environmental Elements Co.)

O&M Practices in Specific Problem Area

The subject of ESP operation and maintenance is a broad one involving all aspects of ESP performance. It covers all the components and all operating conditions. In general, maintenance is considered to be the routine analysis and replacement of ESP components that have failed because of age or abuse. Maintenance requirements can be increased by poor operating practices or reduced by superior system design; however, detailed and exhaustive maintenance practices do not necessarily yield superior ESP performance.

Early identification of O&M problems reduces the extent and the occurrence of excess emissions and allows the plant to schedule outages or make on-line adjustments to maintain production and operate within the prescribed emission limits. The operator should identify those operating conditions or variables that indicate operation outside the accepted norms for a particular boiler/ESP system. (Normal values or conditions are established during the initial performance stack test or are based on the accepted state of the art.) This is generally referred to as baselining, as discussed previously in Section 3.

The boiler-related factors and O&M practices previously described are very important to the performance of ESP's because they affect the major design parameters of the control equipment (i.e., flue gas volume, velocity, and temperature and particulate loading and composition). Proper operation of the recovery boiler will greatly reduce the overall problems with the ESP(s). This section addresses O&M practices that can be implemented to minimize the following potential ESP problem areas:

- Flue gas volume
- Gas distribution and sneakage
- Salt cake removal
- Corrosion

The importance of maintaining adequate corona power and its usefulness in troubleshooting malfunctions of recovery boiler ESP's are also discussed.

Flue Gas Volume--

Because ESP performance is affected by total gas volume, a good operating practice is for the operator or environmental engineer to estimate the volume based on the black liquor firing rate, flue gas oxygen, and temperature. Most plants monitor flue gas oxygen at the economizer outlet rather than at the ESP outlet. An estimate of the flue gas volume must be based on ESP outlet conditions, and the inspector should be equipped with portable temperature measurement equipment (i.e., thermometer or thermocouple) and portable oxygen measurement equipment (e.g., a Fyrite oxygen analyzer). The flue gas volume may be calculated from a plant-specific F-factor (dry standard cubic feet/pound BLS) corrected for flue gas oxygen, moisture, and temperature. (The F-factor for a typical black liquor is approximately 51 dscf/lb BLS.) Temperature and oxygen measurements should be made at the outlet of each chamber where possible (accessible).

The following method is used to calculate the flue gas volume at the ESP inlet or outlet. Corrections made for the flue gas oxygen are for dry standard gas volume, not wet gas volume.

$$Q = \frac{BLS}{min} \; F_{dry} \frac{20.9}{20.9 - \%O_2} + F_z + F_s + F_E \; \frac{T_s + 460 \; °R}{528°F} \qquad \text{(Eq. 1)}$$

where

BLS = black liquor solids firing rate to the boiler.

F_{dry} = F-factor for black liquor solids in dscf/lb BLS.

$\%O_2$ = oxygen content of flue gas at ESP inlet in percent.

F_z = standard cubic feet of water vapor generated from combustion of hydrogen per pound of black liquor solids.

F_E = standard cubic feet of water vapor evaporated in direct-contact evaporator.

F_s = standard cubic feet of water vapor added to flue gas stream as a result of soot blowing.

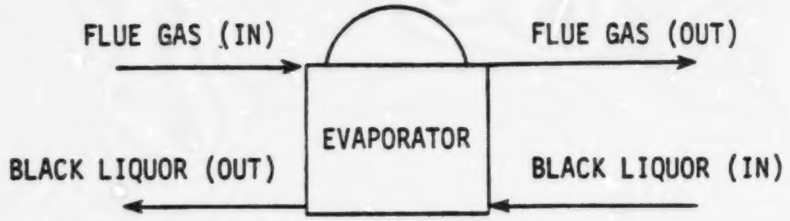
T_s = temperature of the flue gas at the ESP inlet in °F.

The amount of water evaporated in a direct-contact evaporator may be determined by using the liquor flow rates and liquor solids content entering and leaving the unit (see Figure B-11). This method is a simple mass balance based on the assumption that the total amount of solids does not change in the evaporator. This is not strictly true because the liquor does absorb salt cake from the flue gas stream. This effect is considered negligible, however, in the calculation of water lost. If a more exact estimate is desired, estimates of absorption rates can be based on flue gas volume (actual cubic feet/minute) and the uncontrolled boiler dust loading (grains/actual cubic feet per minute). In general, a cascade-type evaporator may remove 50 percent of the uncontrolled particulate. In most units this will increase the total liquor solids mass by less than 5 percent and usually will result in less than a 2 percent error in the real gas stream moisture.

If a more exact or plant-specific value is desired, the F-factor can be calculated from stack gas volume (dry standard cubic feet/minute), flue gas oxygen content, and the firing rate of black liquor solids. When using this method, the operator, inspector, or plant environmental personnel can make this a day-to-day determination of the flue gas volume being treated by the ESP without the expense of conducting stack flue gas volume determinations with a Pitot tube.

When flue gas oxygen increases above normal ranges, the source of inleakage should be identified immediately and appropriate repairs made to reduce the inleakage. Failure to reduce the inleakage will not only cause excess emissions, but the cooling effect of the ambient air may also cause low-power input, excess sparking, and corrosion.

The amount of steam used in soot blowing is not generally measured. Based on discussions with ESP and boiler manufacturers and limited data from pulp mills, however, the value is estimated to be 8 to 10 percent of the rated steam flow of the boiler.[17] The value is expressed in pounds of water vapor per minute, which must be converted to standard cubic feet per minute. The values of F_z and F_{dry} may be compared with the values obtained during a stack test as a check on the validity of the derivation. The variables affecting these values are too numerous to list here, but they include wood



$$\text{water evaporated (lb/min)} = A\ \rho_i - B\ \rho_o$$

where

A = gallons of black liquor to the evaporator

ρ_i = density of black liquor into the evaporator in lb/gal

B = gallons of black liquor from the evaporator

ρ_o = density of black liquor out of the evaporator in lb/gal

$$A\ \rho_i\ \left(\frac{\%\ BLS_i}{100}\right) = B\ \rho_o\ \left(\frac{\%\ BLS_o}{100}\right)$$

where

$\%\ BLS_i$ = solids content of black liquor entering evaporator

$\%\ BLS_o$ = solids content of black liquor leaving evaporator

Figure B-11. Method of calculating additional moisture in the flue gas stream due to direct-contact evaporator.

species and mix, process step variables, quantity of inorganic salt cake recycled to the recovery boiler, percent solids in the black liquor, and heating value of the black liquor.

When the black liquor F-factor is derived from stack tests or by theoretical equations, it is convenient to work in terms of standard cubic feet of gas because this allows for the addition of values without constant correction for different gas conditions. The ESP, however, must be analyzed at the actual gas conditions (i.e., at the measured temperature and oxygen content). Once established, the values of F_{dry} and F_{total} tend to remain relatively constant provided no significant changes in the process occur.

The use of an established F-factor to determine gas flow through the ESP requires relatively little calculation. Only the following are needed: value of the F-factor (dry), firing rate of the black liquor, percent BLS, density of the black liquor, and the temperature and oxygen content of the flue gas.

The ESP dimensions can be obtained from engineering drawings (blueprints). Using these dimensions and the determined gas flow rate will usually produce superficial velocity values that are slightly lower than actual values. The area input into the calculations does not account for the cross-sectional area blocked by the plates and wires. The calculated value should be in the range of 2.5 to 4.0 ft/s, and the lower values generally are recommended. Obviously, as the superficial velocity in an ESP decreases, treatment time will increase. Also, if the superficial velocity exceeds 8 ft/s, not only will the treatment time drop, but reentrainment of captured particulate may occur as a result of the high velocity stripping material off the ESP plate. Thus, it is important to consider the gas volume through the ESP. Gas volume is especially critical if there is a possibility of high excess air levels resulting from air inleakage or improper boiler operation, or if high gas volumes could occur from overfiring the recovery boiler.

Another value that should be checked as an operating practice is the actual SCA. This value relates the total available plate area to the gas volume (ft^2/1000 acfm), and when compared with design or baseline values, indicates ESP performance capabilities. Generally, an increase in the SCA (actual) means improved performance. Other factors are involved; therefore, a comparison of actual SCA with design or baseline values is not meaningful by itself.

Gas Distribution and Sneakage--

Proper gas distribution into the ESP is very important to allow the salt cake particles to have adequate residence time in the ESP. A well-designed distribution system is necessary for good ESP operation. An effective operating practice is to keep the distribution system clean. This is accomplished by rappers and periodic inspection.

Once the flue gas is in the ESP and the electrostatic treatment zone, it must be kept there so that the proper charging and collection of the particulate may occur. A series of baffles perpendicular to the gas path are used above and below the plates to prevent gas sneakage. Gas sneakage allows a portion of the particulate-laden flue gas to bypass the electrically charged area. As a result, collection efficiency is reduced. The installation of these baffles perpendicular to the gas flow gives them a longer path to the gas stream and a resistance to flow. Because gas flow follows the path of least resistance, the gas tends to remain in the electrical treatment zone and gas sneakage problems are reduced.

In otherwise well-designed and well-operated ESP's, gas sneakage and gas distribution problems may account for more than 50 percent of the total particulate emissions. An increase in ESP input power cannot result in the capture of particulate matter in a gas stream that bypasses the treatment zone.

The baffle plates must be designed so that they do not interfere with the normal dust removal system. They must not extend too far below the treatment zone, but they must be low enough to present sufficient resistance to minimize gas sneakage. In wet-bottom ESP's, the proximity of these baffle plates to the black liquor pool may cause them to be subject increased possibilities of acid dew point corrosion. The placement and integrity of these baffles should be checked during each internal inspection.

Salt Cake Removal--

The collected dust removed from the collecting surfaces must be disposed of properly. In the kraft recovery process, the collected salt cake is recycled to the recovery boiler by combining it with the black liquor. This recycling of the salt cake is usually accomplished in the bottom of the ESP. Relatively few recovery boiler ESP's have hoppers. These ESP's are typically flat-bottomed with a ribbon-mixer, paddle-mixer, or drag-chain conveyor to move the salt cake to a pool, trough, or tank of either black liquor or water for recycling to the recovery boiler. Chain breaks, misalignment of the drags, sprocket failures, and/or motor failures are typical malfunctions. Areas near these liquid recycle points and baffles between fields and the shell walls may be prone to corrosion due to heat loss and the raising of the acid dew point temperature. Care must be taken to detect these problems and thus minimize excess emissions.

The conveying system or mixing system must be sized properly to remove the quantity of dust recovered under normal maximum operating conditions. Undersized equipment may allow buildups that can seriously affect long-term ESP performance. In addition, the dust conveyor system must adequately cover the ESP bottom and minimize the area that is "out of reach" of the conveyor system.

The buildup of these deposits or the failing of the conveyor system can have long-term effects on ESP performance. If a buildup were to reach the treatment zone, permanent damage to the ESP components might result, i.e., warpage of the plates or rigid discharge frames and misalignment of wire-weight guide frames. In addition, temporary misalignment of wires or plates may result from the pressure of moving plates and wires, T-R's may be tripped out because of wire plate contact, and resuspension of the dust may occur because of the dust piling up in the treatment zone. The most serious problem, however, is the distortion of the ESP internal components. This distortion will reduce the ESP performance capabilities. The usual indication of a material buildup is the tripping of a T-R set (although there are many other causes for this) along with apparent discharge problems. Records should indicate the time and location of the occurrence, the corrective actions taken, and when normal operations were restored. A gas-load test will provide preliminary indications of permanent damage, and an air-load test should be performed at the next outage to determine if significant damage and deterioration occurred. An internal inspection of the ESP should

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reveal the nature and extent of any damage incurred. In any event, continuous liquor level monitoring is required.

Corrosion--

Corrosion appears to be the most serious maintenance problem in long-term operation of recovery boiler ESP's. Corrosion attacks the ESP shell and internal components. Advanced corrosion is accelerated by air inleakage through corroding areas in the ductwork, around access doors, or in areas near the liquor-flue gas interface in wet bottom units. The rate of corrosion is increased in the colder areas of the ESP. Localized cooling occurs when heat loss through the shell is highest, i.e., where outside stiffeners or structural columns are attached to the shell. Corrosion in internal areas reduces rapper effectiveness so that dust cannot be effectively removed from ESP collection surfaces. In addition, structural members can be weakened or destroyed.

A survey by the Technical Association of the Pulp and Paper Industry (TAPPI) of 19 noncontact recovery boilers installed between 1974 and 1979 indicated that 63 percent had some corrosion problems and 26 percent had severe corrosion problems.[20] Based on the operating conditions of the 19 boilers, the average temperature of those with serious corrosion problems was 361°F. The average temperatrue of those reporting no corrosion problems was 384°F.

The primary corrosive agent in kraft recovery boiler ESP's is sulfuric acid. Flue gases from the boiler contain H_2O vapor with a high concentration of SO_3. The SO_3 vapor combines with the water present to form sulfuric acid vapor (H_2SO_4). As the temperature of the gas stream is reduced, the H_2SO_4 vapor becomes saturated and forms an acid mist.[21]

The most severe area of corrosion in wet bottom ESP's is in the area above the liquid level and below the treatment zone. This area is baffled and is not a part of the main gas volume passing through the ESP. Vapors from the black liquor in the bottom are extremely corrosive. The activity of the vapors increases with high oxygen and sodium sulfide concentrations.[22] Also water vapor raises the local dew point temperature. The temperature of the black liquor is normally below 180°F and results in a cool shell temperature surrounding the liquor. This cool shell temperature results in a gradual decrease in shell temperature between the treatment zone and liquor level. The lower wall temperature is usually below the acid dew point and near the moisture dew point (which is typically around 165°F). The temperature within the ESP is not uniform and the temperature of the shell varies due to contact with structural members, degree of insulation, exposure, and orientation. Areas of low gas circulation in the ESP typically have the lowest temperature and highest rate of corrosion.

The maintenance of a uniformly high temperature in the ESP is important in reducing the rate of corrosion. The temperature may be increased by:

1. Reducing air inleakage
2. Insulating the shell
3. Heating the shell

In general, at flue gas temperatures above 350°F, a well construced, well insulated steel shell ESP will have minimum corrosion. Units with a flue gas temperature between 300° and 350°F have problems in areas of highest heat loss. Units with temperatures below 300°F require supplemental heating. The amount of heating required varies with flue gas temperature, degree of insulation, and other environmental factors such as wind loss and degree of exposure. Generally, the heat requirements are approximately 500,000 Btu/h.[23]

aintaining Adequate Corona Power--

A key indicator of ESP performance is the corona power, which is a useful value for determining whether ESP performance has changed significantly. In general, the corona power in a recovery boiler ESP increases from inlet to outlet, as dust is precipitated out of the gas stream (see Figure B-12). Secondary current values are generally about 0.02 to 0.03 mA/ft^2 in the inlet field and increase to 0.08 to 0.09 mA/ft^2 in the outlet field.

Specific corona power, which may also be calculated for the entire ESP or for individual chambers, is calculated by the following equation:

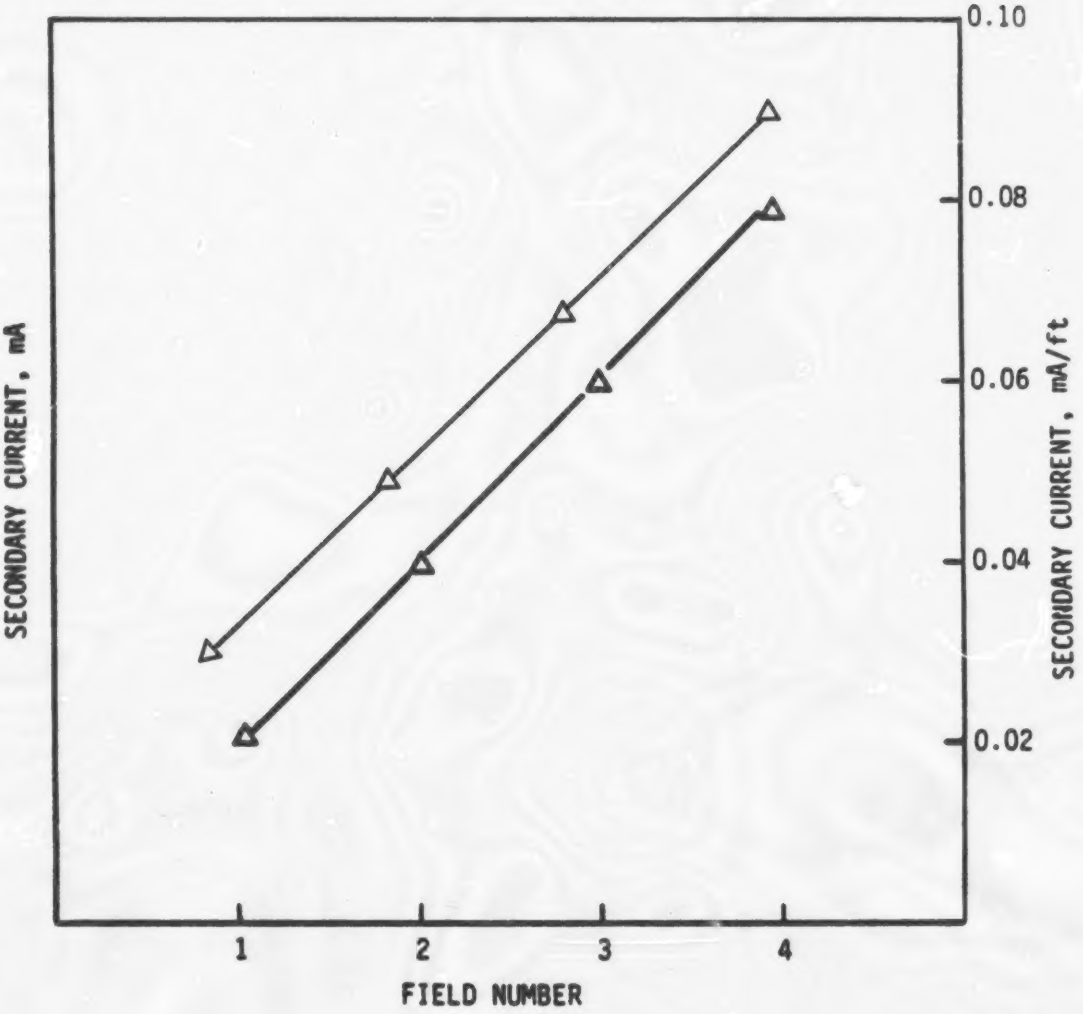

Figure B-12. Examples of optimum secondary current distribution in ESP serving kraft recovery boiler, assuming uniform rapping and wire size in all fields.

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$$\text{Specific corona power} = \frac{\text{total corona power (watts)}}{\text{total gas volume (1000 acfm)}} \qquad \text{(Eq. 2)}$$

The volume obtained by the modified F-factor (divided by 1000) is substituted into this equation. In general, the higher the value of the specific corona power is, the higher the ESP removal efficiency will be. Thus, one may determine whether ESP performance would be expected to increase or decrease by evaluating the specific corona power.

Based on a review of several performance tests and discussions with ESP vendors, the specific corona power needed to meet NSPS for kraft recovery boilers is usually above 400 watts per 1000 acfm. Acceptable performance may be obtained with lower specific corona power values, however, if there are no major problems with power distribution, inleakage, or rapper operation. Equation 2 indicates that a decrease in gas flow through the ESP may improve performance (constant corona power is assumed). The corona power is generally not constant, however; it increases with decreasing gas velocity (volume) because the bulk of the particles do not penetrate far enough into the ESP to inhibit power input. (The opposite is true when gas volume is increased.) Thus, a decrease in gas volume may substantially improve ESP performance. This relationship is an important reason for evaluating firing rates and excess air levels. This specific corona power may be indicative of ESP performance, but should not be used as a sole indicator. The inspector must rely on his/her experience and general knowledge of the ESP applied to the recovery boiler in question to draw any final conclusions regarding overall ESP performance.

To detect and help prevent decreases in corona power caused by misalignment, dust cake buildup insulator failure, etc., the boiler operator should record T-R meter readings at least twice per shift. The operator also should plot ESP power levels by field (inlet to outlet) for each chamber. Deviations from optimum values (determined from baseline or normal values) should be used to evaluate internal ESP conditions and to analyze potential emission levels. If recent V-I curves are not available, the operator should request the plant environmental engineer or electrician to produce a V-I curve for each field. Data from the V-I curves should be used to target the inspection of the rappers, the gas distribution system, and local cooling and to check for inleakage. Serious deviations from normal values should be evaluated with respect to their impact on potential emission levels.

Typically, ESP and boiler operating conditions are not recorded during the stack test period. Without these data, a comparative baseline (w/1000 acfm) cannot be established. The comparative baseline enables the day-to-day operation to be accurately evaluated. Long-term degradation of corona power levels which can occur due to the lost of rapper effectiveness, increases in flue gas volume, misalignment, or changes in T-R set controllers, is seldom noticed over a period of months even though the overall efficiency may be decreasing. In most cases, immediate short-term failures such as rapper control loss, T-R set controller failure, wire breakage, drag chain failure, or insulator failure are indicated by changes in corona power levels that can occur over a few minutes or several hours. Review of corona power levels by supervisory personnel with comparison to normal values on a daily basis can allow rapid and correct diagnosis of maintenance problems before they result in excess emission or catastrophic failure of the unit.

Most recovery boiler ESP's are designed with at least two parallel chambers equipped with isolation dampers. This allows internal maintenance to be performed on one chamber while the other chamber is used to carry the gas volume. However, in order to maintain compliance with emission limits, the boiler load must be reduced to keep the total gas volume compatible with the reduction in collection plate area as a result of passing all the gas through one chamber.

In those systems with a single T-R set per field, the T-R set is installed in a double half wave design. The T-R set controller is typically designed to maximize power input based on the secondary side operating parameters. Power input to the unit is limited by the side with the lowest spark point (i.e., closest clearance, heaviest dust cake buildup, or section with a cold air or oxygen stratification in a single lane). In order to determine if one chamber is limiting total power input, alternate T-R taps should be grounded and the power to each chamber evaluated. Major deviations in voltage or current levels at T-R set limit or spark point indicate clearance problems, rapper failures, or salt cake buildup on the plates.

CONCLUDING COMMENTS REGARDING O&M FOR RECOVERY BOILER ESP's

The person responsible for ensuring compliance with applicable emission limits and for coordinating State and Federal inspections should be familiar with the design, operating variables, effect of changes in process conditions, and maintenance practices with respect to the ESP(s).

Unfortunately, in most pulp mills the analysis of ESP operation is divided among several individuals, none of whom has complete access to all performance data or a detailed understanding of the interaction between the process and the control equipment.

A knowledgeable key person, such as an environmental engineer, should be given the approval of management to review operating records, work orders, and outage reports; make informed analyses of the nature of equipment failures; and help to direct preventive maintenance activities. This key person would be responsible for ensuring that ESP's are properly operated and maintained. He/she should also work hand in hand with the boiler operator to keep him/her informed of effective O&M practices.

As an example of good recordkeeping practices, Figure B-13 presents a specification sheet for a recovery boiler that could be kept by plant personnel. It provides data on heat input, liquor solids rate, steam flow and pressure, and gas volumes specified by the designer. Comparison of these values with actual conditions can help the plant engineer to diagnose ESP malfunctions. Other recommended practices related to the development of a sound O&M plan are discussed in Section 7 (Model O&M Plan). Many of those concepts can be considered applicable to the use of ESP's on recovery boilers.

A	FUEL
BLACK LIQUOR	SPECIFIED BY
	TYPE
ELEMENTAL ANALYSIS	% BY WEIGHT, DRY SOLIDS
	DESIGN PERFORMANCE
	Na
	S
	H
	C
	O
	INERTS
	TOTAL
	GROSS HEATING VALUE, BOF
	BTU/LB DRY SOLIDS
	% BY WEIGHT, AS DELIVERED
	SOLIDS
	WATER
	TOTAL
AUXILIARY FUEL	SPECIFIED BY
	TYPE

		B	PREDICTED PERFORMANCE	
		STEAM	M LB/HR	
				DESIGN PERFORMANCE
		LIQUOR SOLIDS	M LB/DAY	
		EXCESS AIR LVG. BOILER	%	
		B&W BTU-TONS/DAY		
		TOTAL HEAT INPUT	M&B/HR	
		HEAT AVAILABLE TO FURNACE	M&B/HR	
QUANTITY M LB/HR		LIQUOR TO EVAPORATOR		
		SALT CAKE MAKEUP		
		STEAM TO STEAM COIL AH		
		STEAM TO LIQUOR HEATERS		
		FLUE GAS LVG.		
		AIR TO AH		
PRESSURE PSIG		STEAM	OUTLET	
		DROP. DRUM TO SH OUTLET		
		DROP THRU ECONOMIZER		
TEMPERATURE, F		SUPERHEATED STEAM		
	FLUE GAS	LEAVING BOILER		
		LEAVING ECONOMIZER		
		LEAVING EVAPORATOR		
	H_2O	TO ECONOMIZER		
		TO BOILER		
	AIR	TO AIR HEATER		
		LEAVING AIR HEATER		
	LIQ	FROM MEE		
		TO FURNACE		
% LIQUOR SOLIDS		TO EVAPORATOR		
		LEAVING EVAPORATOR		
		TO FURNACE		
RESISTANCE, IN. OF H_2O	FLUE GAS	FURNACE DRAFT		
		BOILER & SUPERHEATER		
		ECONOMIZER		
		EVAPORATOR		
		PRECIPITATOR		
		DAMPERS & FLUES		
		NET CRAFT LOSS		
	AIR	PORTS		
		AIR HEATER		
		DUCTS & DAMPERS		
		NET RESISTANCE		
HEAT DISTRIBUTION		DRY GAS		
		WATER EVAP IN FURNACE		
		WATER EVAP IN EVAPORATOR		
		HYDROGEN IN SOLIDS		
		MOISTURE IN AIR		
		RADIATION LOSS		
		UNACC. FOR & MFRS. MARGIN		
		MOLTEN SMELT		
		REDUCTION OF SALTCAKE MAKEUP		
		REDUCTION OF SULPHUR IN LIQUOR		
		STEAM		

C	EQUIPMENT PER UNIT			
BOILER	TYPE	DESIGN PRESSURE		
	SIZE	MAX IN BLR WATER		
		MAX IN STEAM		
	BOILER H S. SQ FT.			
	DRUM BAFFLE, TYPE			
SUPERHEATER	H. S. SQ FT.	NO. OF STEAM PASSES		
	TUBES, OD. IN	NO. LOOPS	ROWS AT IN	WIDE AT IN
ECONOMIZER	H S. SQ FT	TUBE LENGTH		
	TUBES, OD, IN.	ROWS AT IN	WIDE AT	
	DESIGN PRESSURE, LB/SQ. IN.			
FURNACE	FURNACE VOLUME CU FT.	FURNACE WIDTH FT.	FURNACE DEPTH	
	FURN. HS. SQ FT			
A.H.	TYPE NO.			
EVAPORATOR	TYPE	MAKE	NO./UNIT	
		DIAM FT. WIDTH FT.		
	LIQUOR SPRAY OSCILLATOR NO/UNIT			
AUXILIARY BURNERS	TYPE			
	LOCATION: SECONDARY NO. CAPACITY/BURNER M&B			
	TERTIARY NO. CAPACITY/BURNER M&B			
	STEAM CAPACITY, AUXILIARY BURNERS (APPROX) %			
STEAM TEMP. CONTROL	TYPE			
	LOCATION			
PRI FD FAN	NET REQUIREMENTS LB/HR AT			
	TEST BLOCK SPECS LB/HR AT			
SEC FD FAN	NET REQUIREMENTS LB/HR AT			
	TEST BLOCK SPECS LB/HR AT			
ID FAN	NET REQUIREMENTS LB/HR AT			
	TEST BLOCK SPECS LB/HR AT			

Figure B-13. Typical boiler design specification form of low-odor boiler.

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APPENDIX C

ESP APPLICATIONS IN IRON AND STEEL INDUSTRY

In the steel industry, electrostatic precipitators are used on several different processes, each with unique gas characteristics. Both wet and dry ESP's are used. The range of operating conditions encompasses all of the severe service conditions that were discussed in the main text of this manual. Table C-1 presents a matrix of general service conditions and gas characteristics by process.

Emissions from four sources where ESP's are more commonly applied are discussed in this appendix: BOF primary emissions, sinter plant windbox emissions, coke oven battery stack emissions, and scarfing emissions. The reader is assumed to have an understanding of the processes, which have been widely described in the literature.

The normal maintenance procedures of inspection, lubrication, and record-keeping applicable to any ESP are more critical in steel mill applications because of the harsh, dirty environment, both internal and external, in which ESP's must function. This is particularly true for BOF and sinter plant applications. Areas of concern common to all steel industry ESP applications include:

- Accumulation of dust in dead areas of the ductwork and ESP
- Accumulation of dust and moisture on external structural members, which cause corrosion.
- Vibration and oscillation due to maladjustment of ESP internals resulting from crane movements in the building, railroad movements, and other disturbances.
- Temperature and moisture fluctuations caused by air indrafts from dampers and idle ducts.
- Stress placed on the dust handling component of the system (i.e., hoppers, conveyors, etc.) from high particulate loadings.

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TABLE C-1. RELATIVE SERVICE CONDITIONS AND GAS CHARACTERISTICS

Process source	Heavy dust loading	Erosive particles	Corrosive conditions	Wet Gas condition	Cyclical operation	Explosion potential	Dirty environment	Oily particulate	High resistivity	High temperature	Lime particulate	Process variability	Fine particulate	Predominant type of ESP
Basic oxygen furnace primary emissions	X	X		X	X	X	X			X	X	X	X	Dry
Basic oxygen furnace secondary emissions[a]					X	X	X				X	X	X	Wet
Sinter plant windbox	X	X	X				X	X	X	X	X	X		Wet/dry
Scarfing				X	X								X	Wet
Coke oven battery stacks			X			X	X	X	X	X				Dry
Open hearth furnace exhaust[b]	X	X	X		X	X	X			X	X	X	X	Dry
Blast furnace top gas[b]			X	X		X	X					X		Wet/dry
Coke oven shed gas cleaning[b]			X		X		X	X	X					Dry
Electric arc furnace exhaust[b]	X	X			X	X	X			X	X	X	X	Dry
Coke oven gas tar removal[c]				X		X		X						Wet
Coal preheater[b]		X	X			X	X						X	Dry

[a] No installations in the United States.

[b] Limited applications in the United States.

[c] Process application as opposed to environmental control.

The following sections describe the characteristics and requirements unique to the various steel plant applications. Supplemental detail on process operation, ESP design, and O&M procedures is readily available in References 1 and 2.

BASIC OXYGEN FURNACE (BOF) PRIMARY EMISSIONS

Although the BOF process is the most widely used steelmaking refining process, the last one was built in 1978 at Kaiser Steel.[3] The so-called primary emissions (those resulting from the oxygen blow) are vented to a collection hood and an ESP or scrubber. Secondary emissions are those generated by the charging and tapping operations. Roof-mounted ESP's have been used for control of secondary emissions in Japan, but none have been installed in the United States.

The raw materials (scrap, molten iron, and lime) are charged into the vessel, and pure oxygen is blown into the vessel to burn the silicon and carbon contained in the molten iron. The heat of combustion of these elements is the major source of energy for the process; normally, no external fuel is used. Variations of the process include top blowing, bottom blowing, so-called open hooding, and closed hooding.

This discussion focuses on the top-blown, open-hood version of the process because this is the only configuration in which ESP's are commonly used. This configuration has fallen from favor and no new units have been built in the United States for over 10 years. The more modern BOF's are of the closed-hood design and use high-energy venturi scrubbers. In the open-hood design, the hood that captures the off-gas is elevated above the furnace or "open." This allows large volumes of air to be aspirated into the hood, which burns the CO in the off-gas. Complete combustion is critical to the prevention of explosions in the ESP. Monitoring for explosive gas conditions is necessary in ESP installations, as several explosions have been experienced.

A shop typically has two vessels that operate alternately and use a common ESP. Gas volumes, which can be calculated from the oxygen rate and characteristics of the charge,[4] generally run about 2000 scfm/ton steel. Most furnaces produce 200 to 300 tons of steel per batch, or flow rates on the order of 400,000 to 600,000 scfm. A 250-ton BOF requires a capacity of 775,000 acfm at 550°F and 10 in. H_2O. The gas stream is made up of 234,000 cfm off-gas, 194,000 cfm indraft air, 30,000 cfm air leakage from the down vessel, and 308,000 cfm of water vapor.[5]

The operation of an ESP system applied to a BOF is strongly dependent on the overall gas collection system because conditioning of the gas is required, and failure in any part of the system can cause ESP malfunctions. Figure C-1 is a simplified diagram showing the key elements of a BOF ESP system.

The violent reaction in the refining vessel gives rise to high levels of fine particulate, as shown in Tables C-2(a) and C-2(b). Emissions are highest in the early part of the blow; total emission rate is about 30 lb/ton of steel.[6] A complicating factor in BOF operation is the extreme cyclical nature of the process. The oxygen blowing cycle lasts about 20 minutes. After blowing, the testing, tapping, and recharging operations typically take another 20 to 30 minutes. During these periods, the gas collection system is still drafting; however, the gas volume, temperature, and particulate loading are entirely different from those during the blow. Cooling of the ductwork and ESP during these periods creates a potential for both condensation and warpage. Even during the blowing period itself, the gas flow rate varies widely, as illustrated in Figure C-2. Notwithstanding these conditions, well-maintained and operated ESP's have proven to be very effective control devices on BOF's. Inlet loadings are about 7 to 10 gr/scf, and an efficiency on the order of 99.8 percent is required to meet NSPS and other applicable regulations, which specify about 0.02 gr/dscf. Table C-3 gives performance data on several BOF operations.

The variable gas conditions require gas conditioning. The gas leaving the vessel is 90 percent CO and 10 percent CO_2 at about 3000°F. As the gas is burned by aspirated air in the hood, temperatures in excess of 4000°F can be developed. The first- stage cooling occurs in the water-cooled hood. Hood design is critical and represents a high maintenance item. The characteristics of hood designs are summarized in Table C-4. Although not part of the ESP, a great deal of attention is focused on hood maintenance because of the high cost of hoods and the severe environment in which they operate. Gas leaving the hood enters a water spray chamber for cooling to 600°F or less before it enters the ESP.

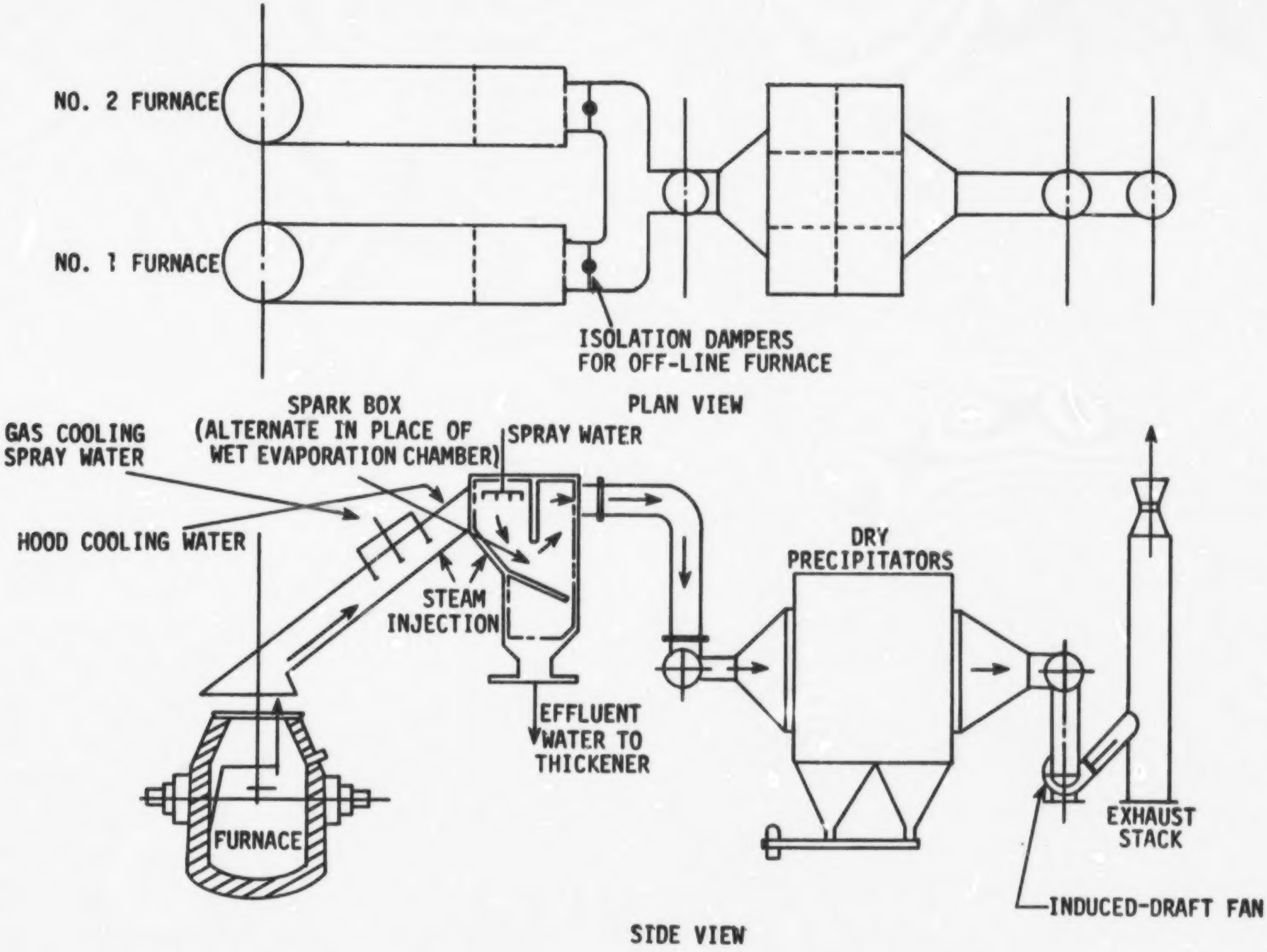

Figure C-1. Typical configuration for a precipitator installed on a BOF.[1]

TABLE C-2(a). TYPICAL PARTICLE SIZE DISTRIBUTION OF OPEN-HOOD, TOP-BLOWN BOF EMISSIONS[6]

Particle diameter, (μm)	Weight percent
<1	25
1-65	15
69-90	20
90-110	15
>110	25

TABLE C-2(b). PARTICULATE COMPOSITION FROM OPEN-HOOD COLLECTION SYSTEMS[6]

Component	Weight percent
Fe total	59
Fe metal	--
Fe as FeO	1.6
Fe as Fe_3O_4, Fe_2O_3	57.4
CaO	2
SiO_2	1

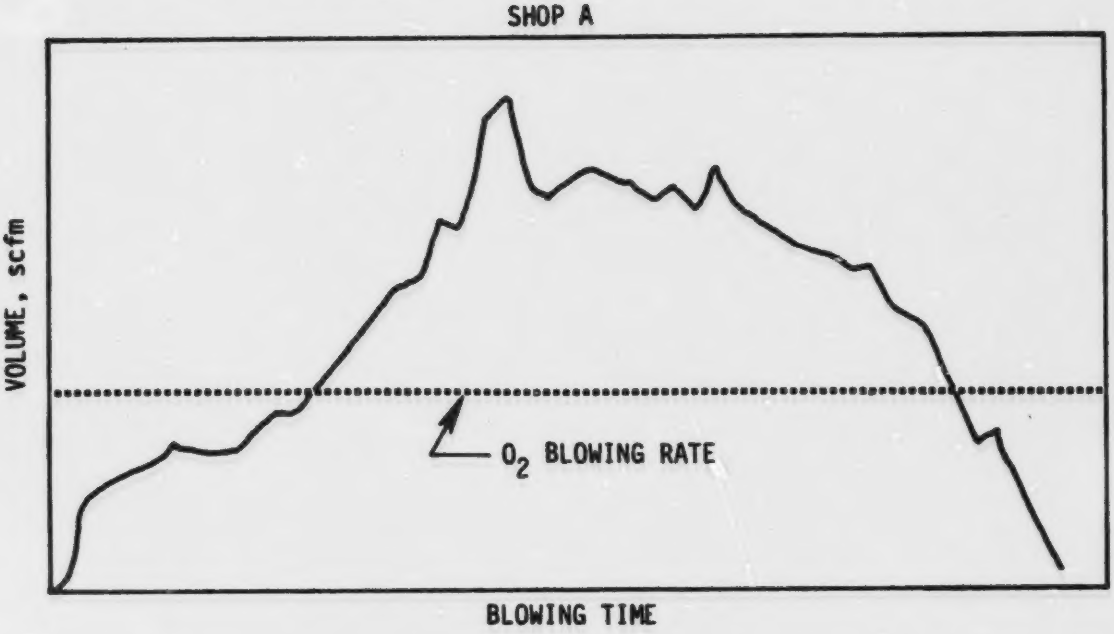

Figure C-2. Variation in gas flow rate from a BOF during the course of a heat.[7]

TABLE C-3. OPEN HOOD SYSTEM PERFORMANCE DATA[a]

Plant	Test date	Emissions (outlet concentration), gr/dscf
U.S. Steel South Works, Chicago, Ill - Scrubber	6/27/77	0.0039
		0.0038
		0.0045
		0.0038
	6/29/77	0.0062
		0.0056
		0.0049
		0.0044
	7/01/77	0.0073
		0.0072
		0.0052
		0.0052
CF&I Steel, Pueblo, Colo. - ESP		
	4/10/78	0.0220
	4/11/78	0.0098
		0.0115
	4/12/78	0.0097
		0.0094
Rebublic Steel, Buffalo, N.Y. - ESP		
	10/20/75	0.0120
	10/21/75	0.0130
	10/22/75	0.0120
Wisconsin Steel, Chicago, Ill. - ESP		
	11/10/76	0.0092
	11/12/76	0.0132
	11/16/76	0.0094
	11/18/76	0.0115
Jones & Laughlin, Aliquippa, Pa. - ESP		
	8/10/76	0.0040
	8/11/76	0.0014
Youngstown S&T, Indiana Harbor, Indiana (now J&L Steel) - ESP		
	6/12/78	0.013
	6/13/78	0.008
	6/14/78	0.012
Crucible Steel Midland, Pa. - Fabric Filter		
	6/11/80	0.0021
	6/11/80	0.0019
	6/12/80	0.0032
	6/12/80	0.0028

TABLE C-4. COMPARISON OF DIFFERENT TYPES OF HOOD CONSTRUCTION[9]

	Refractory-lined	Water-cooled plate panels	Formed panels	Double-pass	Waterwall Boiler	Membrane
Initial cost	Lowest	Low	Moderate	High	High	High
Ability to take high temperature	Poor	Fair	Good	Very good	Very good	Very good
Ability to take temperature change	Poor	Fair	Good	Very good	Very good	Very good
Resistance to slag buildup	Poor	Good	Good	Very good	Fair	Good
Resistance to scaling	---	Poor	Fair	Good	Good	Good
Maintenance cost	Very high	High	Fair	Low	Fair	Fair

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Water sprays are temperature-controlled; additional sprays come on as the temperature rises during the course of the blow. Ideally, all of the water evaporates to avoid caking in the chamber and carryover of water droplets into the ductwork and precipitator. This requires a fine water spray and appropriate nozzles. Nozzle erosion and nozzle pluggage due to dirty water must both be avoided.

During the early part of the blow when the gases are colder, steam is usually injected to maintain the moisture content in the gas. This moisture content and the gas temperature influence dust resistivity, as shown in Figure C-3. Although ESP's are not used on partial combustion (closed hood) systems in the United States, Figure C-4 shows that the general dependence of resistivity on temperature and moisture is the same for the dust from these systems.

When the lime is charged, usually at about the 2-minute mark of the blow, an additional burden is placed on the ESP because of the carryover of lime particles, which have extremely high resistivity.

Electrostatic precipitators on BOF's contain six to eight chambers with three to five fields per chamber. Collection area requirements, as shown in Figure C-5, range from 200 to 600 ft^2/1000 acfm. The newer systems are at the high end of this range, and requirements on some are even higher. The systems are obviously large with concommitantly large fans and ductwork. Multiple fans are used. The ESP should be designed so that each chamber can be isolated for maintenance purposes, and it should be insulated and heated to prevent condensation.

Because of the heavy dust loading, the dust hoppers and screw conveyors are critical elements of the system. Sensors should be used to detect drive or screw failure before dust buildup occurs in the hopper. Hoppers should be sized to hold at least one day's dust accumulation to provide a margin of safety in the event of screw conveyor malfunctions; however, the goal should be to keep the hoppers continuously evaluated. Condensation or external moisture in any part of the system must be avoided because the high lime content of the dust makes it cementitious.

As shown in Figures C-3 and C-4, control of temperature and moisture are critical to ESP performance. Consequently, an evaluation of ESP O&M must include an evaluation of the gas conditioning system. Particularly important

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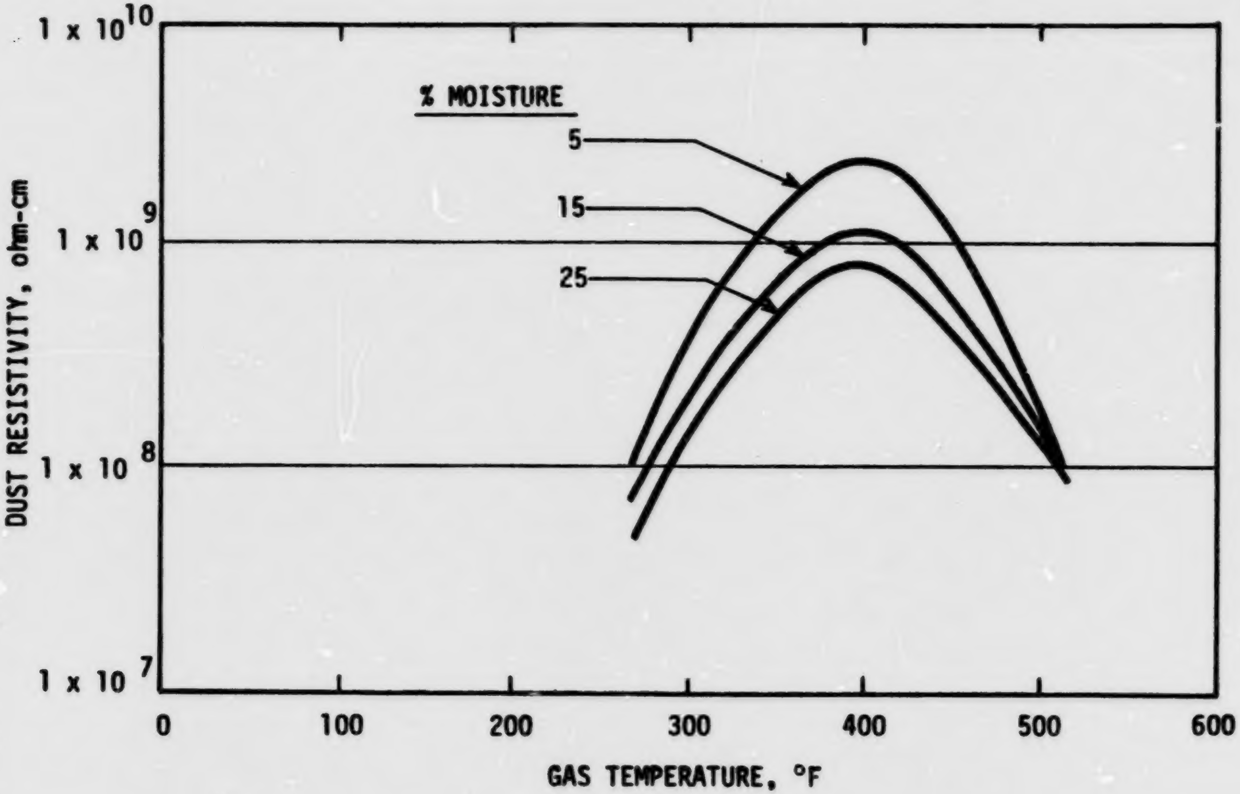

Figure C-3. Resistivity vs. Gas Temperature for BOF Dust.[10]

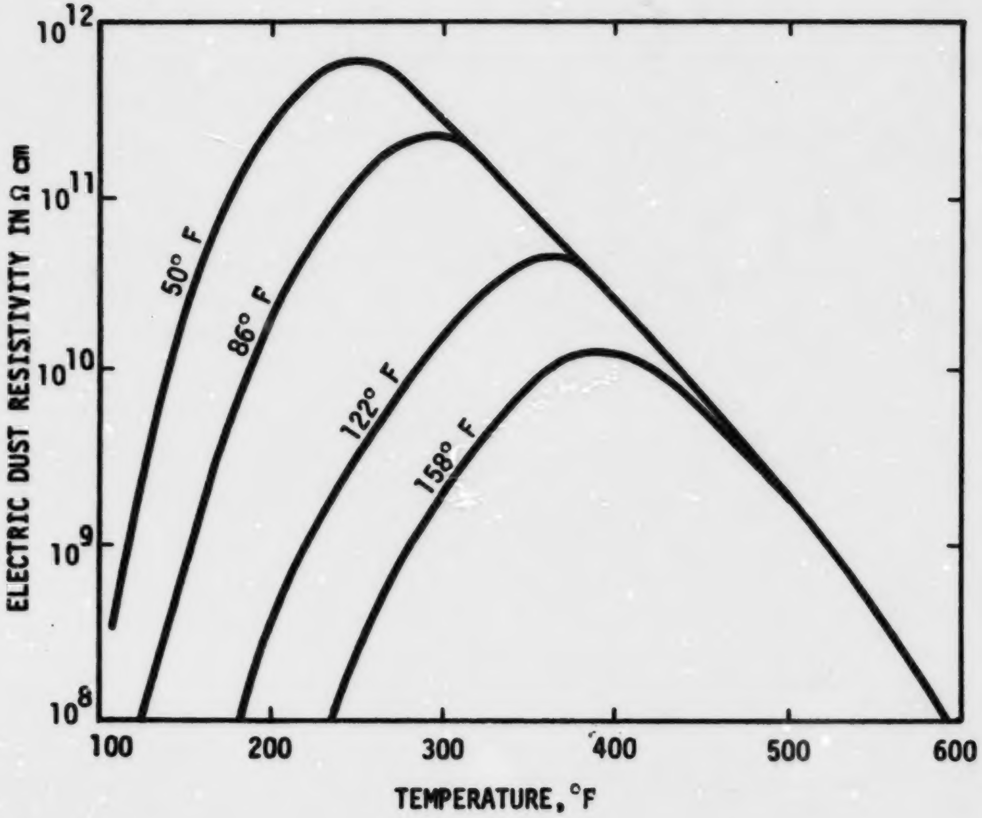

Figure C-4. Electrical resistivity of the partially combusted converter dust.[11]

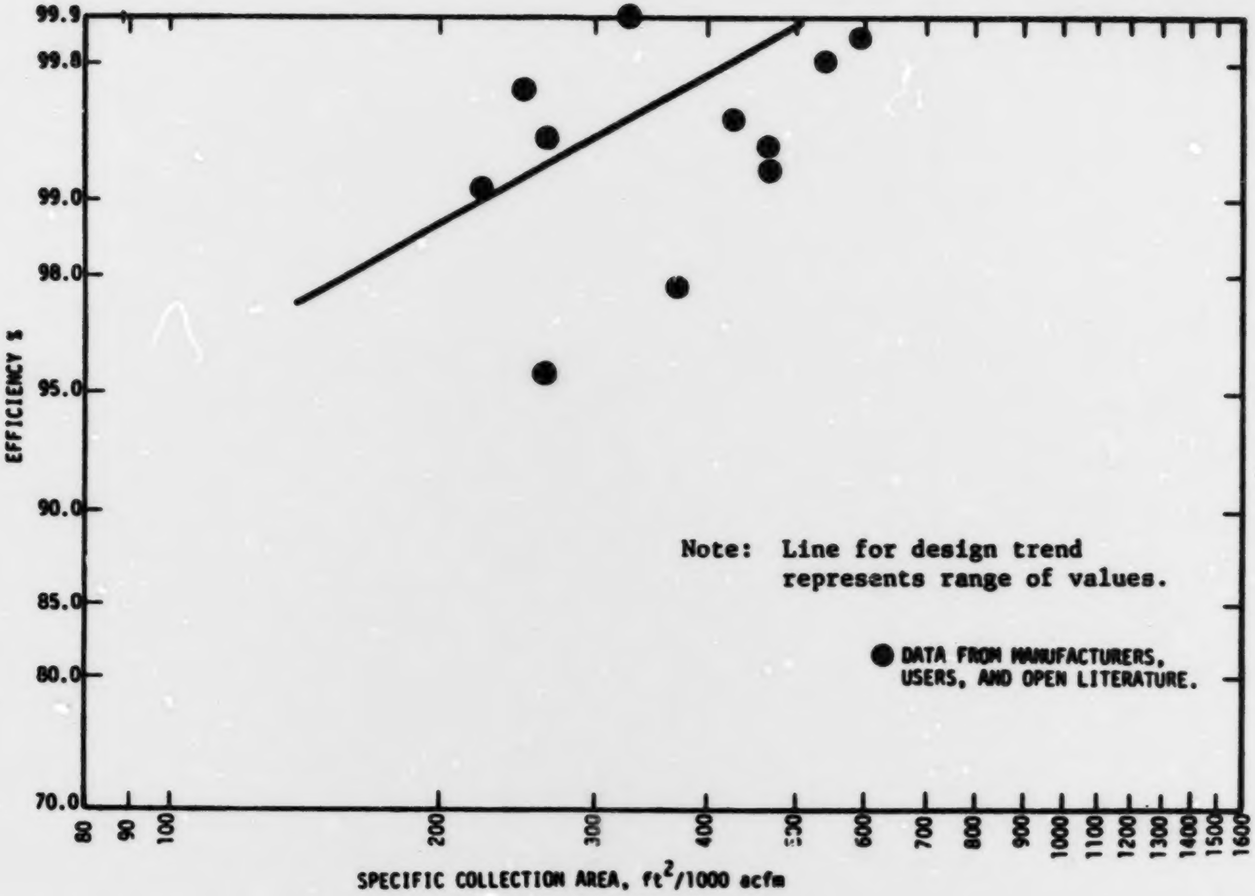

Figure C-5. Selected precipitator correlations for basic oxygen furnace, based on a modified Deutsch Equation.[2]

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are temperature sensors, water spray controls, the steam injection control loop, spray water quality, spray nozzle condition, and indraft air control during nonblowing periods. Dampers can be placed in the inlet to the ESP to minimize the indraft air and the resulting cooling of the precipitator during down periods. All precipitators operate better at a high temperature because of the increased ion mobility in the corona. Excessive temperature must be avoided, however, to control resistivity and to avoid structural impairment of the ESP components.

Because of the severe operating conditions and extremely high efficiency required of BOF ESP systems, a spare chamber and spare fan should be provided to permit the shutdown of chambers for routine inspection. A thorough internal inspection of each chamber should be conducted at least twice a year (preferably once a quarter). This type of schedule means at least one chamber is always under maintenance for repair of broken and misaligned wires, broken insulators, rappers, and screw conveyers.

The recommended minimum instrumentation for a BOF system in addition to that described earlier for any ESP installation includes:[1]

Low pressure alarms:	For instrument air, oxygen supply, lance cooling water, hooding cooling water, service water, waste gas duct, clean gas duct, plant air
Low level alarm:	For hood water cooling tower
High temperature alarms:	For cooling water, dirty gas at sensors and precipitator inlet
Failure alarm:	For precipitator transformer-rectifiers
Vibration sensors and alarms:	For all fans
High bearing temperature sensors and alarms:	For all fans

Many of the above instruments should be equipped with continuous strip charts to record data (e.g., oxygen supply, water flow rates, temperatures at various points, system draft at various points). In precipitator systems, combustible content of gas (or CO concentration) is an additional important process variable that should be monitored, and alarms should be included.[1,2]

At a typical large plant (2.5 x 10^6 tons/year) where good maintenance practices are followed, it takes 75 to 100 hours/week for proper maintenance of an ESP system, including sprays, dust valves, hoppers, and gas cleaning system.[1]

Because BOF shutdowns can be frequent, depending on production schedules, startup procedures for the ESP are important and should include the following fundamentals.

1) Inspection of hoppers and screw conveyors to be sure they are clear of accumulated dust and working smoothly.

2) Air should be allowed to pass through the system to purge the ductwork and ESP of any CO accumulations and to establish a minimum startup temperature of 180°F before the ESP is energized. Radiant heat from the vessel can be used for warmup, or if the system has been shut down for a long period, steam injection can be used. Alternatively, the blow can be started before energization. This, of course, permits essentially uncontrolled emissions during the warmup period.

3) Energization should be in the following order: 1) dust removal system, 2) rapper system, and 3) T-R sets.

The normal operating temperature of BOF ESP's is 500° to 600°F. Alumina insulators permit the ESP to function at temperatures up to 850°F during brief periods of temperature excursion. The alternatives to such excursions are the opening of relief dampers to allow the raw fumes to escape to the atmosphere or the automatic shutoff of the oxygen and retraction of the lance. The structural members of the ESP also must be designed to withstand the higher temperatures during excursions.

Most installations have multiple induced-draft fans. The outlet plenum and gas distribution devices should be designed to maintain uniform flow through the multiple chambers of the ESP. Fans have a tendency to pull more air through those chambers closest to the fan. Unless compensation is made for the changes in the fans that are on line, this can cause excessive gas reentrainment, uneven distribution of dust in the hoppers, and reduction in collection efficiency.

Wire breakage rates of 2 to 200 per year have been reported,[1] but rates on the order of 2 to 10 per year are more realistic.

Table C-5 presents the most common O&M problems encountered in BOF ESP systems.

Two variations in BOF ESP applications that have been applied outside the United States are the roof-mounted ESP for process fugitive emissions and a novel ESP that can operate on partial combustion systems (i.e., high CO in the off-gas). These are not covered here in detail, but the basic arrangements are shown in Figures C-6 and C-7. The roof-mounted ESP (Figure C-6) operates on natural draft without fans and uses wet flushing rather than rappers. The electro-precipitator for partial combustion systems, which has been applied in Europe, addresses the problem of treating explosive gas with high CO content. After it has been cleaned, the gas is usable as byproduct fuel. The torpedo shape of the unit prevents potential stagnant areas where gas could accumulate.

Sinter Plant Windbox Emissions

The sintering process is used to agglomerate fine iron- bearing wastes and fine ores for use in the blast furnace. Combustion air is drawn through the materials, which are bedded on a moving grate (strand), into plenums (called windboxes) below the grate. These windboxes discharge into a header that carries the waste gas to a control device. A cyclone is sometimes used as a precleaner to remove heavy particulate. The windbox gas stream contains 0.5 to 3 gr/scf of particulate and its temperature ranges from 200° to 400°F. The temperature can fluctuate widely during startup and shutdown and cause the gas to pass through its dewpoint. This is especially critical for gas with higher acid concentrations. The particulate is extremely abrasive. If roll scale or other oily material is used in the raw material mix, the exhaust contains unburned hydrocarbon aerosols, which are extremely difficult to remove and can cause ESP fires. At temperatures above 200°F in the outlet side of the ESP, oil volatilizes and fine metal particles oxidize, which causes self-ignition. These "glow fires" can ignite carbon and oil mist in the ESP.[14] The exhaust contains 100 to 500 ppm of SO_2 from sulfur in the mix. This creates low pH and corrosive conditions in wet systems. The

TABLE C-5. BOF ESP OPERATION AND MAINTENANCE PROBLEMS[1,13]

Problem	Cause	Potential Remedies
Corrosion of collected surfaces, especially at the bottom zone of the outlet half of ESP	Condensation due to gas temperature going below dew point.	• Warmup after shutdowns. • Control of cold air indraft from down vessel or other sources. • Steam injection during early part of blow to maintain temperature. • Maintenance of air seals on hoppers to prevent cold air indraft. • ESP insulation and/or heating.
Structural damage to ESP	Alternate heating and cooling. High temperature excursions.	• Avoidance of temperature overloads through temperature control system and water sprays on gas. • General operation to maintain as steady state temperature as possible. • Design of structural components to withstand temperature.
Insulator burnout and subsequent shorting out of sections	Moisture and dust buildup on insulators.	• Avoidance of condensation, as described above. • Providing fan and filter to supply air to insulator housing. • Frequent (once/week) inspection.
Broken wires	Moisture and dust buildup on wires.	• Avoidance of condensation, as described above.
Performance degradation due to poor gas conditioning	Deviation of gas temperature and moisture from ideal range.	• Frequent inspection and replacement of water spray nozzles. • Use of clean or treated water to avoid nozzle pluggage; use of scale inhibitors. • Inspection and calibration of temperature control loop.
Insulator failure	High temperature excursions.	• Temperature control by use of water spray system. • Use of alumina insulators. • Provision of fan and filter to supply air to insulator housing. • Frequent inspection.
Fan/motor failure	High temperature. Bearing failure. Vibration.	• Frequent cleaning of motor cooling fins in dusty environment. • Bearings with temperature alarm. • Vibration sensor and alarm.
Malfunction of dust removal equipment	Broken screw conveyer shafts. Plugged dust valves. Dust bridging in hopper. Hopper heater failure. Hopper Vibrator failure.	• Conveyor on/off indicator lights • Level indicators in hoppers, preferably high and low level. • Regular dust removal schedule. • Frequent inspection (daily).

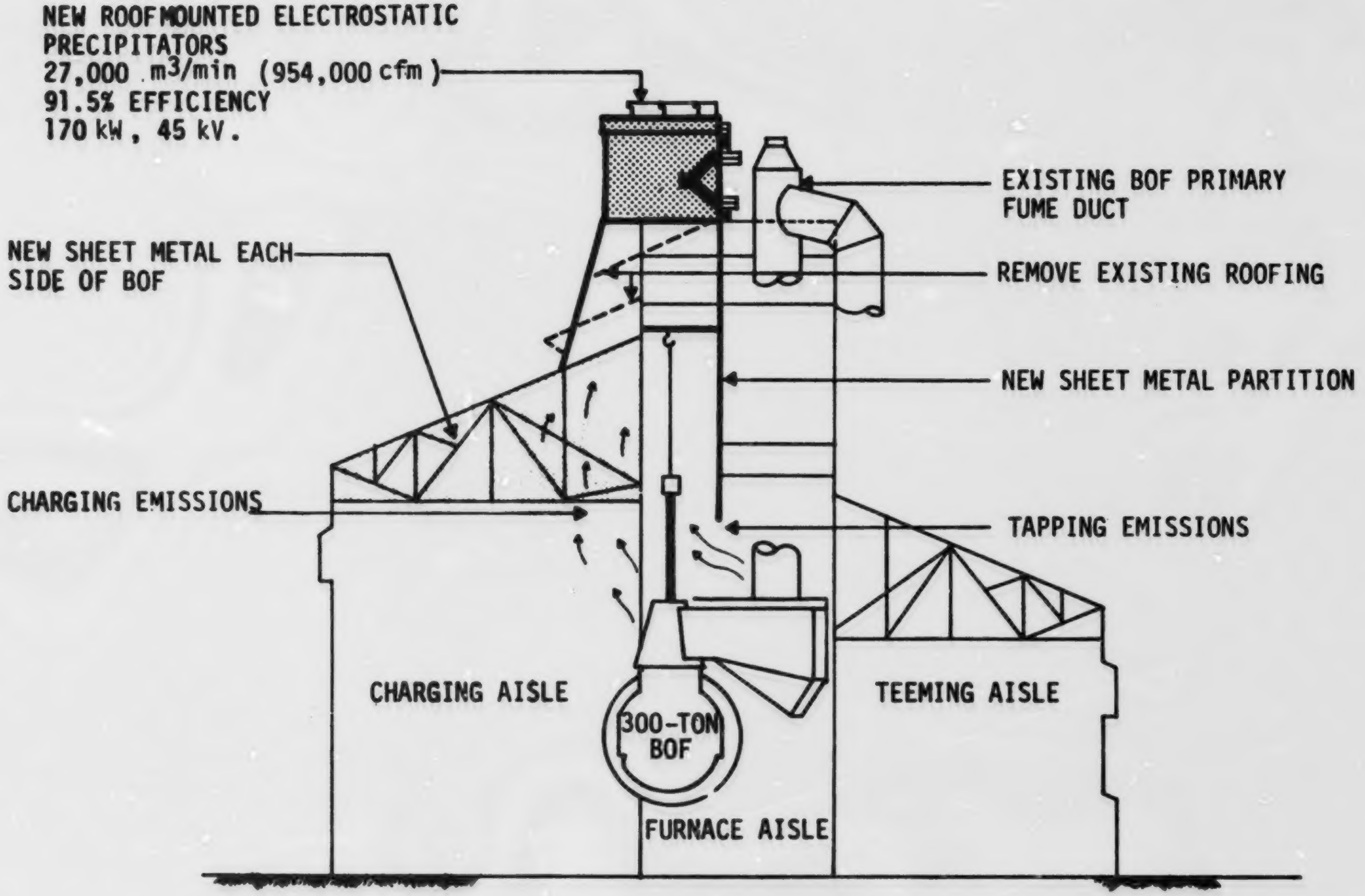
NEW ROOFMOUNTED ELECTROSTATIC PRECIPITATORS
27,000 m3/min (954,000 cfm)
91.5% EFFICIENCY
170 kW, 45 kV.
EXISTING BOF PRIMARY FUME DUCT
NEW SHEET METAL EACH SIDE OF BOF
REMOVE EXISTING ROOFING
NEW SHEET METAL PARTITION
CHARGING EMISSIONS
TAPPING EMISSIONS
CHARGING AISLE
TEEMING AISLE
300-TON BOF
FURNACE AISLE

Figure C-6. Cross section of BOF having roof-monitored ESP.[12]

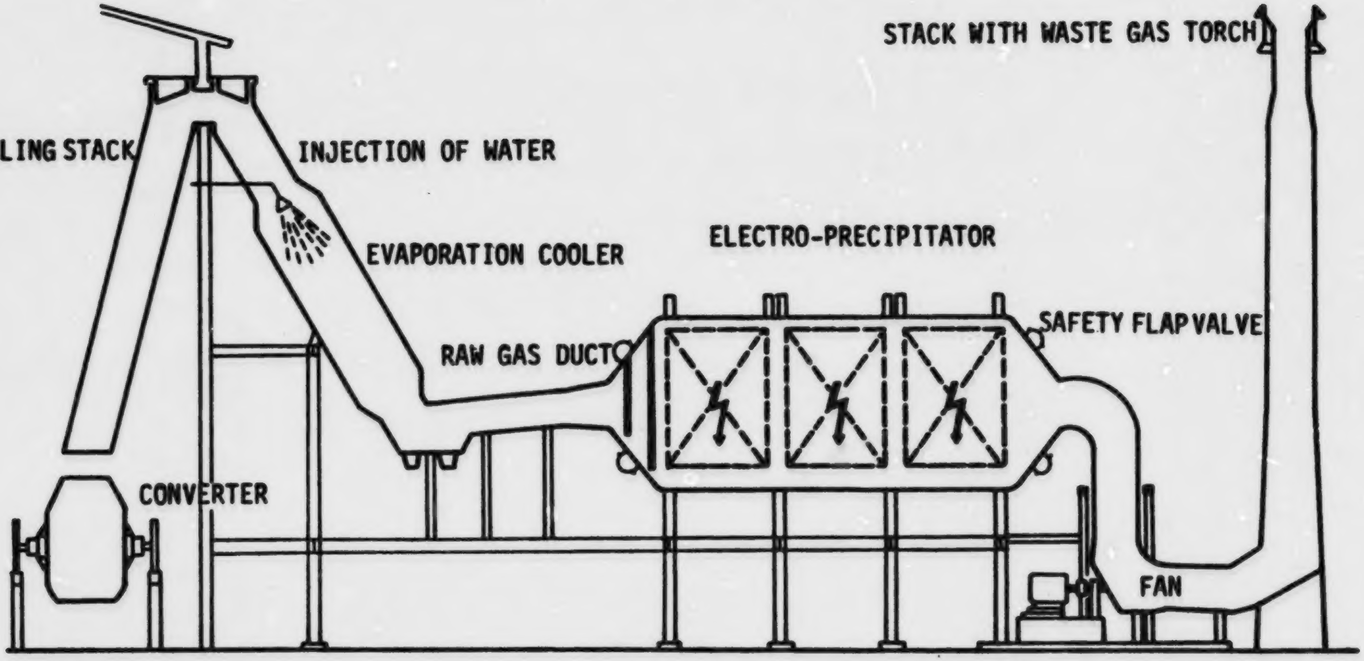

Figure C-7. BOF and Q-BOP waste gas dust collection plant.[11]

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sometimes significant alkali and fluoride content of the raw materials can cause acid attack of even stainless steel components.

Sinter plant windbox emissions have been controlled by scrubbers, wet ESP's, dry ESP's, and fabric filters; the high-pressure drop scrubbers appear to be the most effective (>60-in. w.c.).

A typical particle size distribution in the windbox gases is as follows:[2]

15 to 45% < 40 μm
9 to 30% < 20 μm
4 to 19% < 10 μm
1 to 10% < 5 μm

The chemical composition of windbox dust is highly dependent on the raw materials used. Table C-6 presents a range of composition. Emission rates from the windbox average 11.1 lb/ton of sinter. Precleaning with a cyclone removes the heavy particles, which amount to about 20 percent of the total. The particulate loading entering an ESP is therefore about 8.7 lb/ton.

TABLE C-6. CHEMICAL COMPOSITION OF SINTER STRAND WIND BOX DUST[2]

Compound	Wt %
Fe_2O_3	45-50
SiO_2	3-15
CaO	7-25
MgO	1-10
Al_2O_3	2-8
C	0.5-5
S	0-2.5
Alkali	0-2

The flow rate depends on grate area, as shown in Figure C-8. The sintering process is operated as a continuous process, and except for the raw material mix, operating conditions are usually uniform. The plant is typically shut down for maintenance once a week for a period of one shift.

The particulate, which consists mainly of metallic oxides, silica, and limestone, is very resistive. As indicated in Figure C-9 it may be the order of 10^{11} to 10^{14} ohm-cm. This limits the current densities and the applied

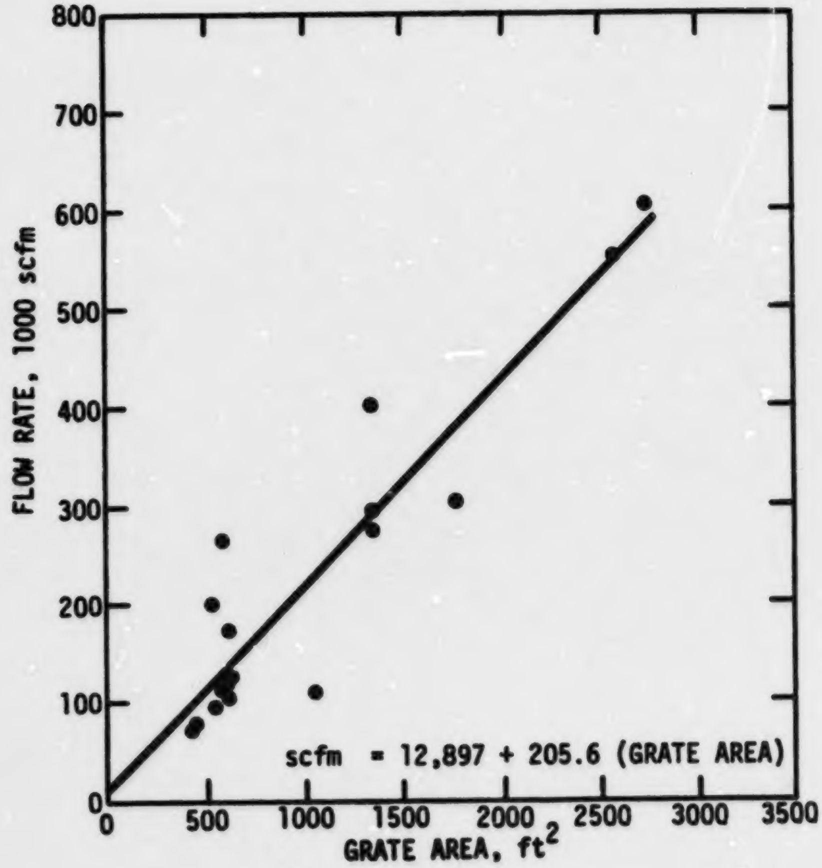

Figure C-8. Flow required for sinter plant windbox control.[15]

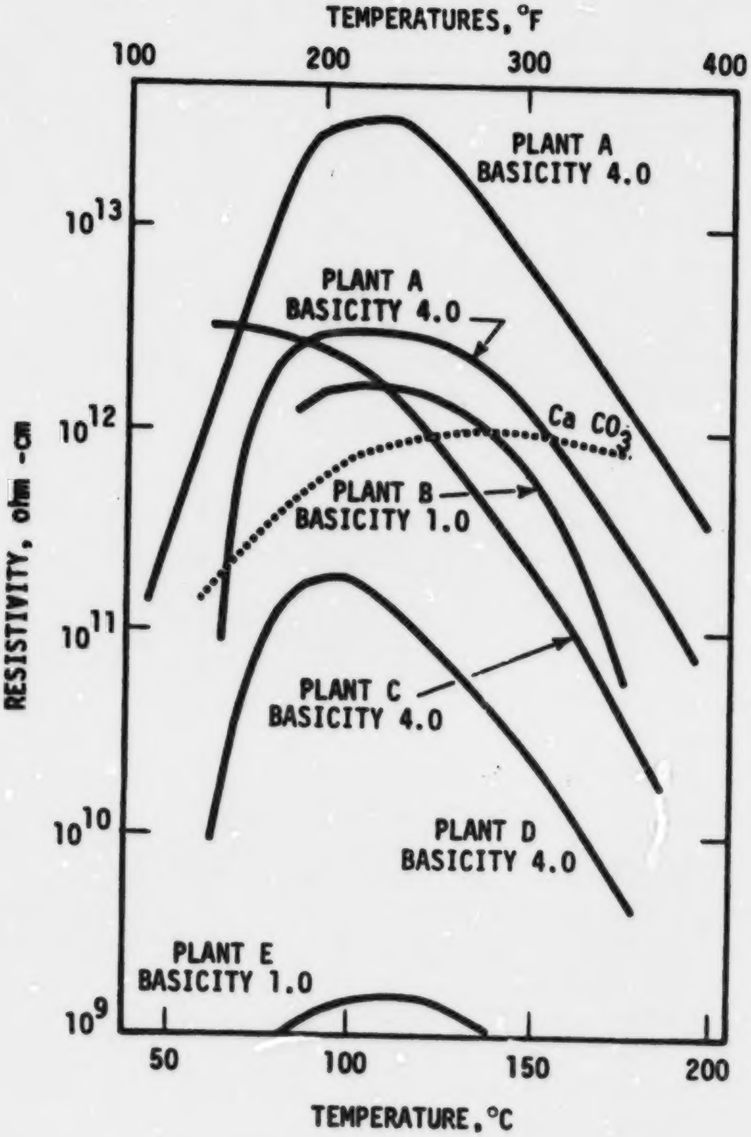

Figure C-9. Effect of temperature and sinter basicity on resistivity of sinter-plant particulate.[2]

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voltage at the discharge electrodes to avoid back corona formation. Thus, the particle charging process and the electric field at the plates for particulate collection are marginal. This situation appears to be analogous to the behavior of high-resistivity fly ash found in some utility applications.

As the basicity [i.e., the amount of limestone (or dolomite) used in the mix] increases, resistivity also increases and causes degradation in performance. More rapping and less gas velocity can overcome this effect to some extent, but dry ESP collection is not generally effective at the high basicity (2.5 or more) used in modern sinter plants.

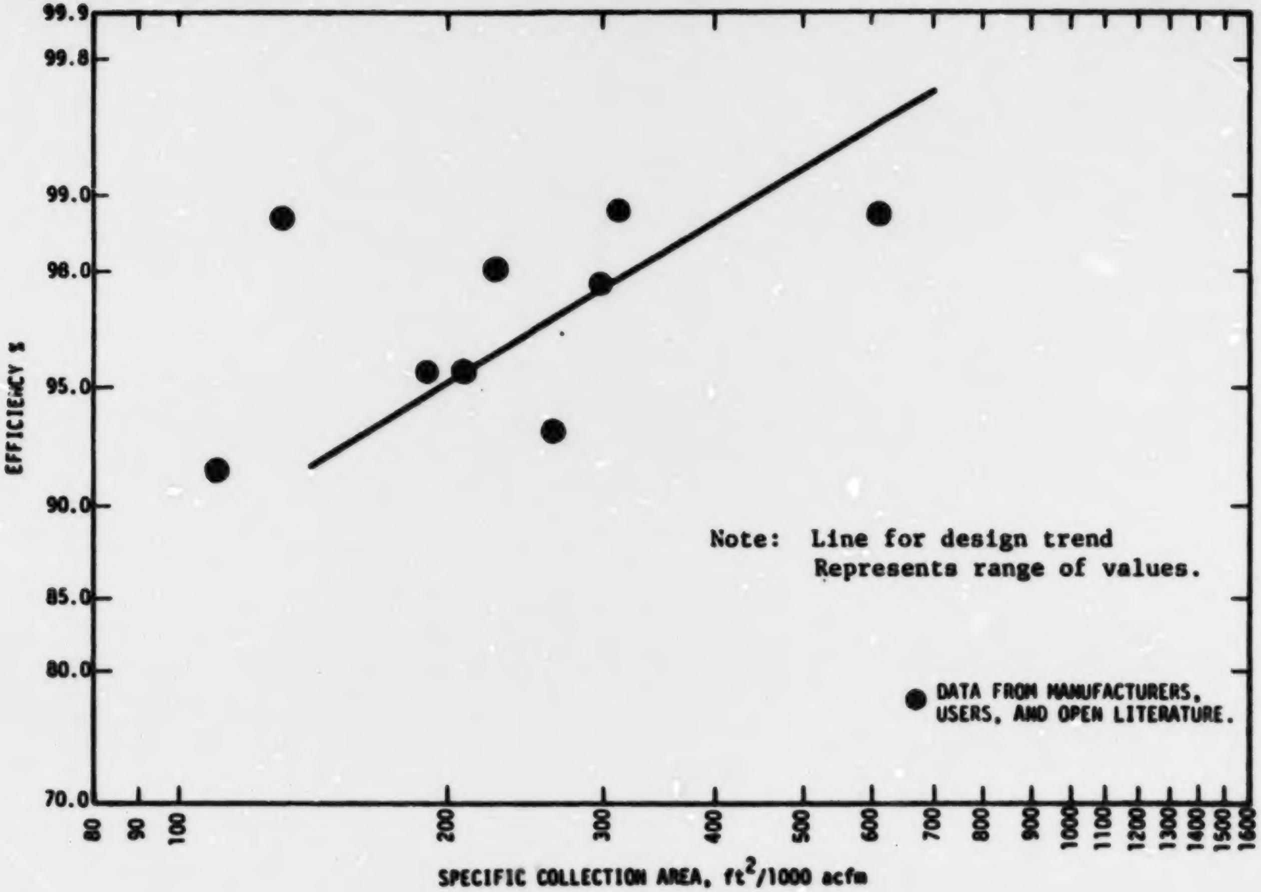
Figure C-10 shows the collection area requirements for ESP's operating on sintering machines equipped with mechanical collectors. Typically, single-stage, horizontal-flow units have been used. Carbon steel is the predominant material of construction, even though acid corrosion is a major concern. The power supply generally consists of a single-phase, high-voltage transformer; appropriate control equipment; and a bridge rectifier circuit. The latter may use mechanical-type rectifiers, the newer Kenotron vacuum tubes, selenium rectifiers, or silicon rectifiers. Normal transformer ratings are between 25 and 50-kVa, 440 volts (primary), and 50 to 75 kV (secondary). The collection area consists of dust-collection electrodes with high-voltage discharge electrodes uniformly spaced and of uniform length.[15]

Collection efficiency on the order of 98 to 99 percent is required to meet typical state regulations. Average design parameters to achieve this are:[10]

Gas velocity	4.3 ft/s
Inlet gas temperature	245°F
Electric field	8.1 kV/in.
Inlet dust loading	1.0 gr/acf
Precipicator power	71 watts/1000 cfm

Even with these parameters, opacity regulations may be impossible to meet because of the opacity associated with fine hydrocarbons that pass through the ESP.

The materials charged to the sinter machine can change during process cycles (depending on the availability of wastes, ore fines, lime, etc.), and these changes can affect the properties of the dust. Gas conditioning is not used in the sinter plant application of ESP's. The basicity of the sinter



Note: Line for design trend
Represents range of values.

Figure C-10. Selected precipitator correlations for sintering process, based on a modified Deutsch Equation.[2]

far override any other factor in influencing resistivity. Changing to superfluxed sinter (basicity 2.5 to 3.5) has reportedly caused collection efficiency to drop 30 percent.[16]

In an attempt to address the resistivity and oily aerosol problem, wet ESP's have also been used on windbox exhaust streams. Control of liquor pH by caustic addition is essential in wet systems.

Table C-7 lists sinter plant process variables that can affect ESP performance. Table C-8 presents specific O&M problems.

A sinter plant has many raw material conveyors and material transfer points, which are often vented to either the windbox or the discharge-end control device. Careful consideration must be given to the design and operation of auxiliary venting and collection from these points to avoid flow imbalance and gas temperature and moisture fluctuations. Some plants have multiple sinter strands vented to the ESP. In these cases, the startup of one strand while the other is on line can cause cold air to enter the system and create condensation of moisture or acid gas.

When the sintering machine is started after a shutdown, it takes about an hour for the process to reach full operating temperatures. During this time, condensation may take place in the ductwork and in the dust collection equipment. The ESP's are usually not powered fully until the gases have become warm enough to evaporate the condensed moisture. A cold startup will result in an hour or so of uncontrolled emissions. As a result of normal downturns, startups can occur once a week. The following startup procedures are paraphrased from reference 15.

1. Use a roll of paper to cover the empty strand. Remove the paper when it reaches the discharge end of the machine.
2. Start sinter cooler fans.
3. Start hearth layer conveyors (if a hearth layer is used)
4. Start the dust conveyors that take the collected dust from the windboxes and emissions controls and return it to the feed system.
5. Start windbox control unit.
   a. The dust conveyors must be running before the power unit can be started. After startup, the interlock is bypassed and the ESP continues to run.

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TABLE C-7. PROCESS PARAMETER CHECKLIST FOR SINTER PLANT WINDBOX CONTROLLED BY ESP

Process parameter	Deviations from normal practices	Effect on ESP
Raw material mixing	Improper mixing	Unsintered portions will generate emissions and increase the load on the ESP. Excess emissions from ESP stack.
Usage of BOF dust	Higher usage	Excessive fine materials; increased emissions; increased KCl and NaCl emissions.
Usage of mill scale	Higher usage	Excessive hydrocarbons; increase in opacity (bluish color); danger of ESP fires.
B.F.[a] flue dust	Higher usage	Increased emissions of chlorides (KCl and NaCl)
B.F. Sludge	Contaminated with oil	Excessive hydrocarbons; increased opacity.
Basicity	Higher basicity (>1.0)	Increased resistivity of limestone particles; reduced ESP efficiency (5 to 10%).
Sulfur throughput	Higher-sulfur material	Corrosion problems in ESP due to SO_2
Ignition	Improper ignition	Unsintered portions will generate emissions and place excessive load on ESP.

(continued)

TABLE C-7 (continued)

Process parameter	Deviations from normal practices	Effect on ESP
Burn-through	a) Slower than normal	Unsintered portions generate emissions and place excessive load on ESP.
	b) Faster than normal	High slag formation, bad sinter quality, low gas flow rate to ESP.
Gas temperature	a) Higher than normal	Higher volumetric gas flow through ESP than the designed value; poor gas distribution and reduced efficiency.
	b) Lower than normal	If below dew point, acids formed because of SO_2 presence will lead to higher corrosion of ESP parts.
Grate maintenance	Poor maintenance	Unsintered material falls through the sinter bed and increases the load on ESP.
Sinter machine seals and ductwork maintenance	Poor maintenance; excessive air leakage	Higher volumetric gas flow through ESP than the designed values; poor gas distribution in ESP; and reduced ESP efficiency.

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[a] B.F. = blast furnace.

TABLE C-8. SINTER PLANT ESP O&M PROBLEMS

Problem	Cause	Potential Remedies
Fires, explosions	Self ignition of oily matter and carbon in ESP outlet or dust bins	° Maintain outlet temperature at 200°F or less. ° Minimize oily raw materials. ° CO monitors and alarms in ESP outlet.
Fan/motor failure	High temperature Bearing failure Vibration	° Frequent cleaning of motor cooling fins in dusty environment. ° Bearings with temperature alarm. ° Vibration sensor and alarm.
Dust removal equipment manfunction	Broken screw conveyer shafts Plugged dust valves Dust bridging in hopper Hopper vibrator failure	° Conveyor on/off indicator lights ° Level indicators in hoppers, preferably high and low level. ° Regular dust removal schedule. ° Frequent inspection (daily).
Corrosion of internals	Temperature excursion below dewpoint	° Minimize indrafts. ° Avoid auxiliary vents on conveyor transfer points. ° Temperature sensors/alarms. ° Careful startup/shutdown procedures.

After starting the dust conveyer system, determine that air (414 kPa, 60 psig) is available for rapper controls; provide power to the rapper control panel; turn on suspension insulator electric heaters; determine that all grounding switches are properly set and all doors closed and locked; admit air to the precipitator; allow 60 minutes for warmup to drive off any condensed moisture from the insulators; put ESP power supply into operation; after about one minute to warm up tube filaments, apply plate voltage; review readings of current and voltage to the primary of the high voltage step-up transformer and the voltage drop across the power saturable reactor; review power output as shown by control potentiometer.

Note: Admitting air to the ESP involves startup of the windbox fan. The load on this fan is regulated by a hydraulic-electrical mechanism that adjusts the fan inlet damper. The regulator will maintain a manually set inlet section pressure control point. When the main draft fan is stopped, the regulator automatically closes the inlet damper to prevent cold air inleakage to the ESP.

The regulator hydraulic pumping unit must be started before the fan can be started. After the regulator is started, the draft fan is started according to the following steps: turn on the excitation power supply (normal or emergency) for the motor field; actuate the switches of the high-voltage switch gear unit; start the motor; after allowing some 20 seconds to accelerate to full speed, automatically apply the field at the proper instant, and pull into synchronization. If starting is unsuccessful, the high-voltage circuit breaker will trip out, and a waiting period is required before attempting to restart.

To stop the windbox fan, first trip the fan switch. Interlocks reset the regulator timer, close its contacts, and thus drive the damper to its closed position. The a.c. power for field excitation is then turned off, and the regulator pump unit is stopped.

6. Start sinter machine.

Wet ESP's have been demonstrated as capable of controlling windbox exhaust emissions. A continuous water washing of the plates prevents an insulating layer of pollutants from forming and nullifies the effect of the increased resistivity of the particles caused by superfluxing the sinter. The gas stream is kept saturated by continuous sprays; as the particles and liquid droplets collect on the plates, a film forms that continuously drips off and carries with it the collected dust, and thus prevents any buildup.

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The approximate water requirement for this type of system is 5 to 9 gal/1000 scf.[17]

The water sprays reduce the temperature of the inlet gases to 100° to 120°F; therefore, the condensible hydrocarbon portion of the total particulate emission is available for collection. Some hydrocarbons condense into a fine mist and are collected on the plates. These small-sized hydrocarbon particles have a low dielectric constant and are not removed as efficiently as dust particles with dielectric constants greater than 10.

The maximum inlet loading for proper operation should be 0.25 gr/scf, which could be achieved by installing a primary mechanical collector upstream. Also, the pH of the recycled water should be monitored and a caustic solution should be injected to neutralize any acidity. The combination of chlorides, fluorides, alkalis, and SO_2 places great stress on the materials of construction.

Coke Oven Battery Stacks

Unlike the two previous applications, the control of coke oven battery stacks is a relatively recent development (within the last 5 years). Only four to five batteries have installed or experimented with ESP control of emissions. Battery stack emissions are the products of combustion of the fuel gas used to heat the coke oven batteries. This gas can be coke oven gas, blast furnace gas, natural gas, or a mixture of these. Because these gases are relatively clean, control would not be necessary were it not for coal particles and pyrolysis products leaking from the coke oven chamber into the flue chamber. When this leakage cannot be controlled by maintenance of the refractory dividing wall between the oven and the flue, a control device must be installed in the exhaust duct. Thus far, all such installations are retrofits; no new coke oven battery has been built with a control device on the stack.

The complicating factors in ESP application are the extremely low resistivity of the particles, which are predominantly carbon; the tarry nature of the emissions; and the sporadic nature of leakage. Although the overall battery operation is generally uniform and continuous, leakage may be from only certain ovens and occur at specific times during the cycle resulting in a "puffing" nature of the emissions.

Particulate emissions range from 2.6 to 124 lb/h[18] and average 29.5 lb/h. The flow rate from a single battery ranges from 30,000 to 80,000 dscfm and is proportional to the capacity of the battery and the excess air used for firing.[18] Exhaust temperature is in the range of 400° to 600°F.[18] Depending on the fuel used, the gas stream can contain up to 3500 ppm of SO_2.[18] Moisture content ranges from 5 to 15 percent.[18] Particle sizing is given in Figure C-11. Electrostatic precipitators have not been particularly effective in particulate removal, as reflected in Table C-9.

The dry ESP's used are similar to those used in coal-fired powerplants. The design incorporates high SCA (333 to 880 ft^2/1000 acfm), multiple stages, and low gas velocity. Design parameters are given in Table C-10. MRI suggests that units should be insulated to avoid corrosion and that dust hoppers should be heated and equipped with vibrators and hopper sides inclined at 60 degrees or more.[20] The poor performance (even at high SCA's) is attributed to the low inlet dust loading and the low resistivity of the carbon particulates. Because carbon releases the charge imparted, the particles avoid collection; they bounce off the collecting electrode and become reentrained in the process.

Operating experience is insufficient for the development of specific operation and maintenance guidelines. One company has noted visible sparks in the dust bin and ignition in the hoppers. Another found it necessary to replace the vibrator-type rappers with electromechanical rappers and to pressurize insulator compartments and circulate heated (250°F) air through these compartments.[20] The poor performance of dry ESP's suggests application will not be widespread.

A pilot-scale test was run with a wet ESP at a battery that has since been shut down. This trial produced a particulate removal efficiency of about 93 percent. The gas flow rate to this pilot-scale unit ranged from about 800 to 3000 acfm. The unit contained a low-energy (1/2 in. w.c.) fiberglass venturi gas-conditioning scrubber to cool the gas, achieve uniform velocity, and remove larger particles. The design of the wet ESP section was unconventional in that a water film on concentric plastic rings served as the collecting electrode. No water spray was included; estimated water requirements were 230 gal/min for a full-scale unit (equivalent to 3.3 to 3.8 gal/1000 acf).[19]

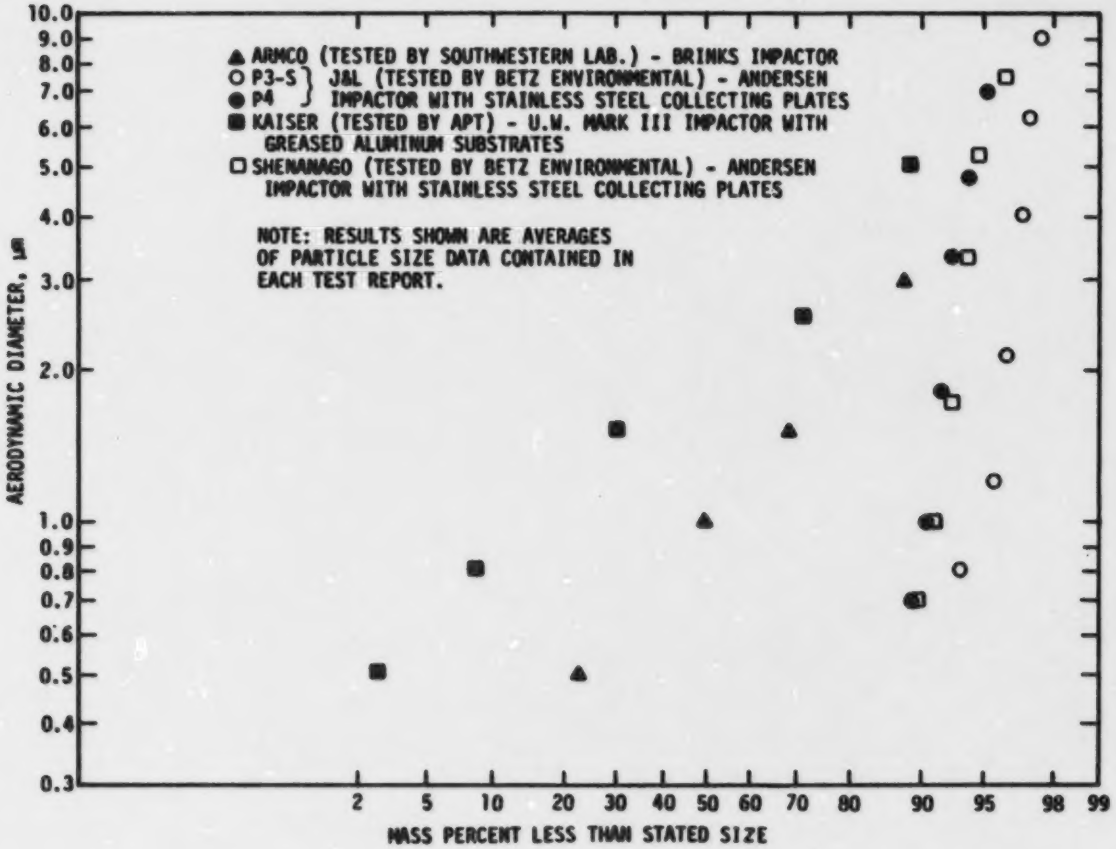

Figure C-11. Coke oven particle size distribution determined by use of cascade impactors.[18]

TABLE C-9. PERFORMANCE DATA FOR ELECTROSTATIC PRECIPITATOR CONTROL OF COKE OVEN BATTERY STACK PARTICULATE EMISSIONS[19]

	Particulate loading,[a] (gr/dscf)		Collection efficiency, weight %	Outlet particulate emissions, lb/ton
	Inlet	Outlet		
Lone Star Steel E. B. Germany Works Batteries A and B[b] (February 1973)				
Test 1	0.051	0.043	12.9	0.35
Test 2	0.046	0.031	32.7	0.24
Test 3	0.081	0.039	49.8	0.31
Armco Steel Houston Works Battery 1 (November 1976)				
Test 1	0.009	0.009	2.2	0.09
Test 2	0.008	0.048	33.9	0.05
Test 3	0.007	0.004	45.6	0.04
Armco Steel Houston Works Battery 2 (November 1976)				
Test 1	0.075	0.013	80.2	0.10
Test 2	0.033	0.006	79.4	0.05
Test 3	0.113	0.011	89.4	0.09
National Steel Granite City Battery C (July 1979)				
Test 1	0.403	0.370	Neg.	6.27
Test 2	0.162	0.164	Neg.	2.81
Test 3	c	0.105	c	c

[a] Probe, cyclone, and filter catch (EPA Method 5)

[b] Combined stack.

[c] Invalid sample.

TABLE C-10. COMPARISON OF ESP DESIGN AND PERFORMANCE CHARACTERISTICS AT LONE STAR STEEL, ARMCO STEEL HOUSTON WORKS, AND PILOT TEST UNITS[17]

	Armco Steel Unit No. 1	Armco Steel Unit No. 2	Lone Star Steel	Precipitator, "Dustmobile"[a]	United McGill "Mobile EP"[b]
Plate area, ft^2	40,720	14,585	37,599	940	632-1868
Plate-to-plate spacing					
(a) Inlet, in.	9.0	9.0	9.0	9.0	-
(b) Outlet, in.	9.0	9.0	9.0	9.0	0.075
Corona wire diameter, in.	0.092	0.092	0.092	0.092	0.075[j]
Specific collection area, ft^2/1,000 cfm	582[c]	582[c]	342[c]	77-218	202-966
Migration velocity, in./s					
(a) Design	0.37[d]	0.37[d]	1.00[d]	-	-
(b) Actual	0.00-0.2[e]	0.61-0.80[e]	0.10-0.2[f]	0.40-2.16	0.10-1.20
Gas velocity, ft/s	2.06	2.06	4.2	1.5-5.0	1.9-5.3
Secondary voltage,[g] kV	45 (average)	(45 average)	(55 average)	-	19-28
Current density,[g] m-amps/ft	0.059 (avg)	0.062 (avg)	0.066 (avg)	0.1844	i
Electrical sets, total number; configuration	3 in series	3 in series	3 in series	1	3 in series
Mass efficiency, %					
(a) Design[h]	72.9	72.9	82.1	NA[k]	NA
(b) Actual	44.1	83.1-90.2	24.4-40.6	19.2-69.5	35.3-96.1
Materials of construction					
Casing	ASTM A-36	ASTM A-36	ASTM A-36	NA	NA
Hoppers	ASTM A-36	ASTM A-36	-	NA	NA
Discharge electrodes	316 (stainless steel)	316 (stainless steel)	304 (stainless steel)	NA	NA
Collecting surfaces	Mild steel	Mild steel	ASTM A-36	NA	NA

[a] Pilot test unit--data from Lone Star Steel Company; tests performed at E.B. Germany Works, Batteries A and B (common stack), Lone Star, Texas.

[b] Not directly comparable, thickenss of discharge electrode plate.

[c] At maximum design flow rates.

[d] Calculated from design specifications by using Deutsch's Equation.

[e] Calculated by using Deutsch's Equation from acceptance test report: Armco Steel Corporation. "Sampling and Analysis of Particulate Emissions from Inlet and Outlet of Coke Plant East and West Precipitators, "Houston, Texas, November 16-18 and 22, 1976. Based on total particulate catch.

[f] Calculated by using Deutch's Equation from acceptance test report: Lone Star Steel Corporation, "Source Emissions Survey of Lone Star Steel Plant, Coke Oven Electrostatic Precipitation, Lone Star, Texas, February 1983," Ecology Audits, Inc. Based on total particulate catch.

[g] Design basis.

[h] Ratings at maximum inlet grain loading.

[i] Not directly comparable, secondarly current readings varied from 4-6 ma/field.

[j] Replaced with 316 (stainless steel) following unit startup.

[k] Not applicable.

Wet ESP's have an inherent disadvantage of cooling the exhaust gas and causing a loss in draft. This shortcoming necessitates the addition of an induced-draft fan and complicates battery drafting, which is ordinarily accomplished by natural draft.

Two suppliers (Mikropul and Fluid Ionics) reportedly offer wet ESP designs for application in coke battery stacks. The wet ESP offers the advantages of higher collection efficiency due to lower particle reentainment, smaller space requirements, and fewer sparks and fires. Corrosion potential, drafting control, the need for water treatment, and the attendant costs are the offsetting factors.

Scarfing Emission

In the scarfing process, high-purity oxygen is blasted against the surface of the rolled or cast steel as it exits the rolling mill or continuous caster while it is still hot (1600° to 2000°F). This process removes surface defects. It generates relatively low emissions of extremely fine particulate, consisting almost exclusively of iron oxide. The process is intermittent in that individual slabs or billets are scarfed on a piece basis. Generally, a piece passes through the scarfing machine every 2 to 4 minutes, which generates in a burst of emissions lasting 10 to 20 seconds. The scarfing application is generally less demanding than the BOF or sinter plant. Emission rates are lower; the process variability is minimal; the size of the equipment is much smaller, and the emissions are relatively consistent in size, composition, and temperature. The complicating factors are the fine particle size and intermittent nature of the emissions.

The exhaust from the scarfing machine enters a smoke tunnel (duct), where water sprays cool the gas and provide some cleaning action. Prior to environmental controls, the gas was exhausted to the atmosphere after this step. As in the case of sintering, the opacity of the exhaust has generally been more difficult to control than the mass emission rate.

Flow rates for scarfing range from 25,000 to 125,000 scfm.[21] Inlet grain loading varies from 0.25 to 1.25 gr/acf. The resistivity of scarfing fumes is shown in Figure C-12. Wet ESP's are used almost exclusively for scarfing control because of the saturated gas conditions.

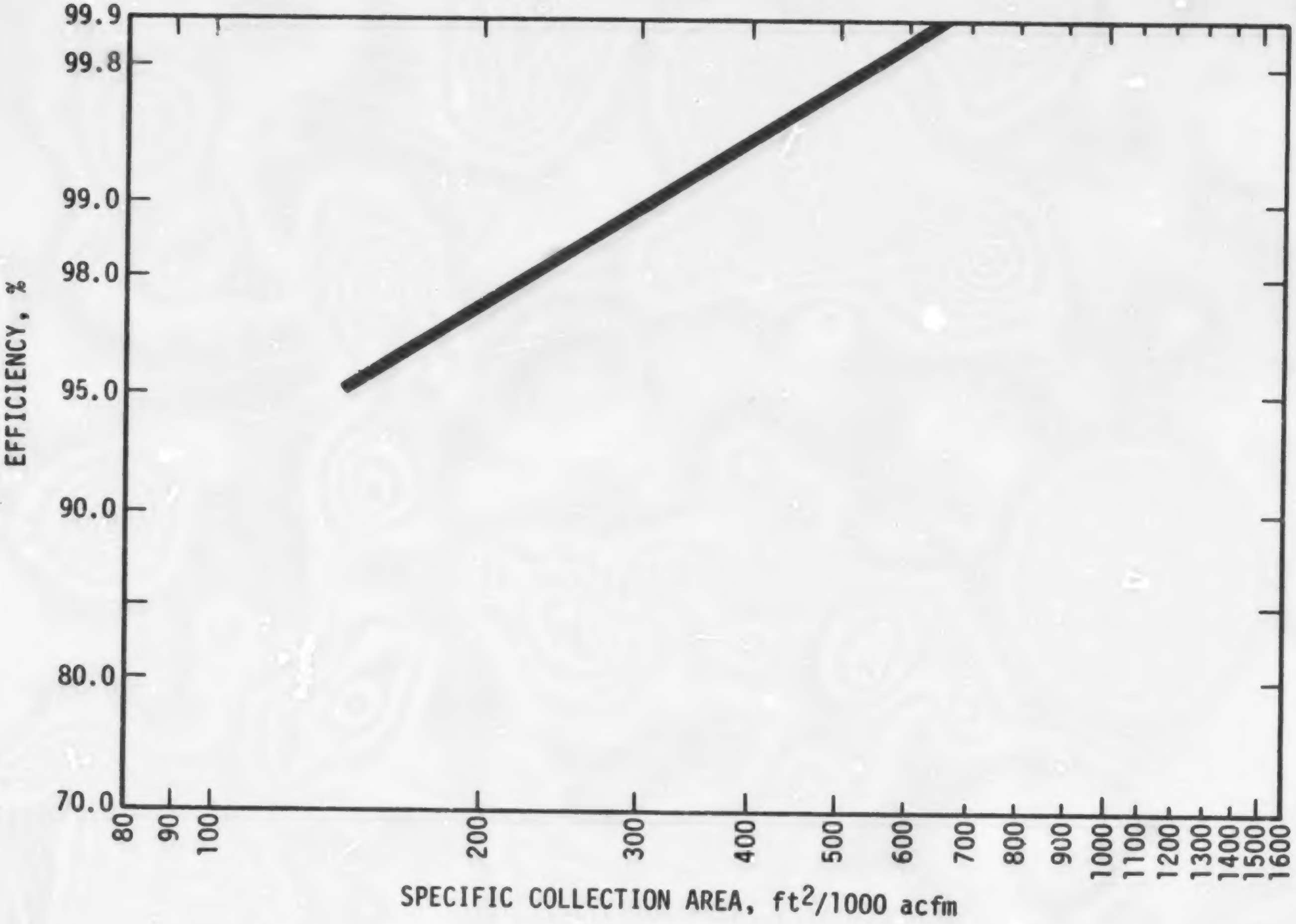

Figure C-12. Specific collection area requirements for scarfing emissions.[2]

Wet ESP's can be categorized structurally as either plate-type or pipe-type, the latter being used principally on scarfing operations. The pipe-type usually has a weir-overflow arrangement or a continuous spray with an upward vertical gas flow. Plate units have either a combined presaturation/continuous spray or a spray with intermittent wash and horizontal or vertical gas flow.

Certain characteristics of the wet ESP make it an attractive alternative to wet scrubbers, dry ESP's, or fabric filters. The moisture-conditioning effect eliminates the problem of high resistivity and minimizes reentrainment. No rapping mechanism is required and pressure drop is low. Its disadvantages are that it has a high potential for corrosion and scaling and it requires a water treatment system.

Although the use of wet ESP's appears to be a viable technology for particulate control of sintering and scarfing operations, design data are generally considered confidential because of the intense competition between manufacturers.

Wherever components of a wet ESP are similar to those of a dry precipitator, the operation and maintenance procedures discussed previously can be considered generally applicable.

Plate-Type (Horizontal Flow) ESP's--

The effluent gas stream is usually preconditioned to reduce temperature and achieve saturation. As it enters the inlet nozzle, the gas velocity decreases as a result of the diverging cross section. At this point, additional water sprays may be used to effect good mixing of water, dust, and gas and to ensure complete saturation of the gas before it enters the electrostatic field. In addition, baffles are often used to distribute the velocity evenly across the inlet of the ESP.

Within the charging section, water is sprayed near the top of the plates in the form of finely divided drops that become electrically charged and are attracted to the plate. This gives the plates an even coating of water. Solid particles, which are simultaneously charged, "migrate" to the plates, where they become attached. Since the water film is moving downward by gravity on both the collecting and discharge electrodes, the particles are captured in the water film, which drains from the bottom of the ESP as a slurry.

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Concentric-Plate Type ESP's--

When applied to scarfing operations, this ESP uses an integral tangential prescrubbing inlet chamber followed by a vertical wetted-wall, concentric-ring ESP chamber.

The concentric cylindrical collection electrodes are wetted by fluids dispensed at the top surface of the collection electrode system. The discharge electrodes consist of an expanded metal system with uniformly distributed corona points formed on a mesh background. This type of discharge electrode system is supposed to provide a combination of a high, nearly uniform electric field associated with a parallel plate system and a nearly uniform corona current density distribution associated with the closely spaced corona points on the electrode system. Higher gas flows can be handled by the addition of more concentric electrode systems and by increasing the length of each electrode.

Conventional Pipe-Type ESP--

The pipe-type configuration is preferred over the plate-type for scarfing applications because it appears to distribute water better during the washing cycle. Weirs are also used in some cases to ensure that the tubes are kept clean.

The actual system consists of a number of vertical collecting pipes. In the center of each is a discharge electrode (wire type), which is attached to the upper framework and held taut by a cast iron weight at the bottom. The lower steadying frame keeps the weights and wires in position.

The upper frame is suspended from high-voltage insulators housed in compartments on top of the ESP shell. Heating and ventilating systems help to prevent moisture and dust from accumulating in the insulator compartments.

The washing system usually consists of internal nozzles located at the top of the pipes. At specified intervals (after approximately 20 cycles), this system thoroughly washes the tubes. While the washing is taking place, the louver damper to the exhaust fan is closed to prevent droplet carry-over.

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Pre-startup Procedures

Before initiating the startup of ESP's, all of the major items of equipment, connecting pipes, lines, and auxiliaries must be inspected, cleaned, and tested, as follows:

- Check for adequate flow, leaks, and pressures in all lines.
- Check orientation of nozzles.
- Inspect drain system.
- Check all clearances between piping and high-voltage system.

ESP Internals--

- Inspect all high-voltage system connections to transformer-rectifier (T-R) sets, bus ducts, and grid.
- Check insulators for cleanliness, cracks, and chips.
- Check to see that high-voltage bus ducts to insulator connection are tight.
- Check heaters and pressurizing fan to be sure they are in proper operating condition.
- Check seals on access doors and plates and make sure that the interlock contact is good.

T-R Sets --

- Check oil level.
- Tighten electrical connections.
- Check to see if ground switch is operating properly

Control Panels --

- Check all fuses and make sure indicator lamps for all high-voltage items, heaters, and blowers are functioning.

Startup Procedures

- Turn heaters on.
- Energize pressure blower.
- Turn high-voltage circuit breaker on.

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- Activate spray system, allowing sufficient time to clear air from lines.
- Open damper to introduce effluent gases.

Shutdown Procedures

- Close inlet damper.
- Deenergize ESP.
- Shut down spray system.
- Allow heater and blower system to remain energized to prevent accumulation of moisture on the high-voltage insulators.

Normal Operation

Heaters and blowers are energized during normal operation. The spray system is always activated just prior to energizing the high-voltage system. The gas flow is monitored by damper, and water pH must be monitored at the waste discharge.

Inspection and Maintenance During Normal Operation

Actual inspection and maintenance practices are very system-specific, and the manufacturer's instructions should be followed closely. Because ESP's operate with very high voltage, the system's internals must be properly grounded.

General inspection and maintenance practices are briefly outlined below.

Mechanical Maintenance--

All internal components should be checked for alignment, excessive dust buildup, tight bolts, structurally sound welds, and general structural integrity of the cross bracing and other support members. Because the support insulators perform such a vital function in electrostatic precipitation, the structural support end of the high-voltage insulator in the high-voltage housing must be thoroughly inspected for cracks, chips, etc.

Water System--

All pumps, internal spray nozzles, and related valving and piping should be checked. Because nozzles are subject to plugging, they should be routinely disassembled, cleaned, and/or replaced as necessary. The main water-pressure

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supply pumps and all pipe joints must be checked for leaks, and all couplings must be checked for tightness. Nozzle orientation also should be checked to ensure that the intended spray pattern is being achieved. Regular attention also should be given to the recirculated water system to maintain the strict water quality requirements necessary for successful wet ESP operation.

Electrical System--

General areas to check include the high-voltage control panel, the heater and blower control panel, high-voltage insulators, heater system thermostats, T-R sets, and all related electrical connections.

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APPENDIX D

ESP APPLICATIONS IN MUNICIPAL INCINERATORS

INTRODUCTION

The primary purpose of most municipal incinerators is to reduce the volume of solid waste for easier disposal. By adding the appropriate equipment, some facilities are able to use the heat released in the furnace to produce steam for either heating or electrical generation and thus derive secondary benefits from the process. Both ESP's and wet scrubbers are used to control particulate matter emissions from municipal solid-waste-reduction incinerators. Although ESP's require a relatively large initial capital expenditure compared with that for scrubbers, they have generally been the preferred method for controlling particulate matter emissions because of the high operating costs, water treatment, sludge disposal, and corrosion concerns connected with the use of scrubbers.

The application of ESP's to this particulate emission source can be quite difficult because of the typical wide variations in the as-fired heat content, moisture content, and size of the refuse being burned as fuel that must be faced daily. These variations make it difficult to maintain adequate control of the combustion process, and good combustion is essential to the proper operation of an ESP.

CHARACTERIZATION OF MUNICIPAL INCINERATOR OPERATION

Most incineration systems distribute the "fuel" onto a series of grates to volatilize and combust the material. Incinerator sizes vary widely, ranging in feed capacities from 50 to over 600 tons/day of solid waste. Examples of municipal incinerators with and without heat recovery are shown in Figures D-1 and D-2, respectively. Several different grate designs are used, but inclined reciprocating grates seem to be preferred. Usually these

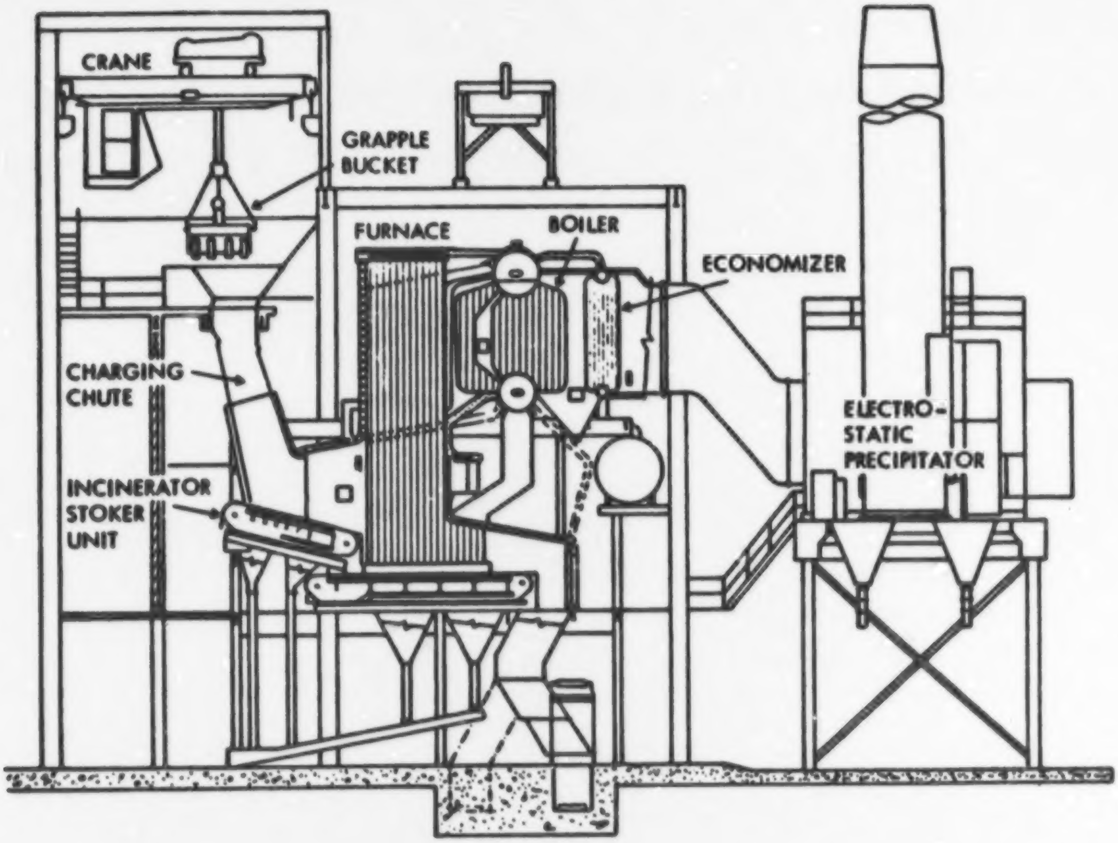

Figure D-1. Diagram of a 120 ton/day municipal incinerator equipped with heat recovery and an ESP.

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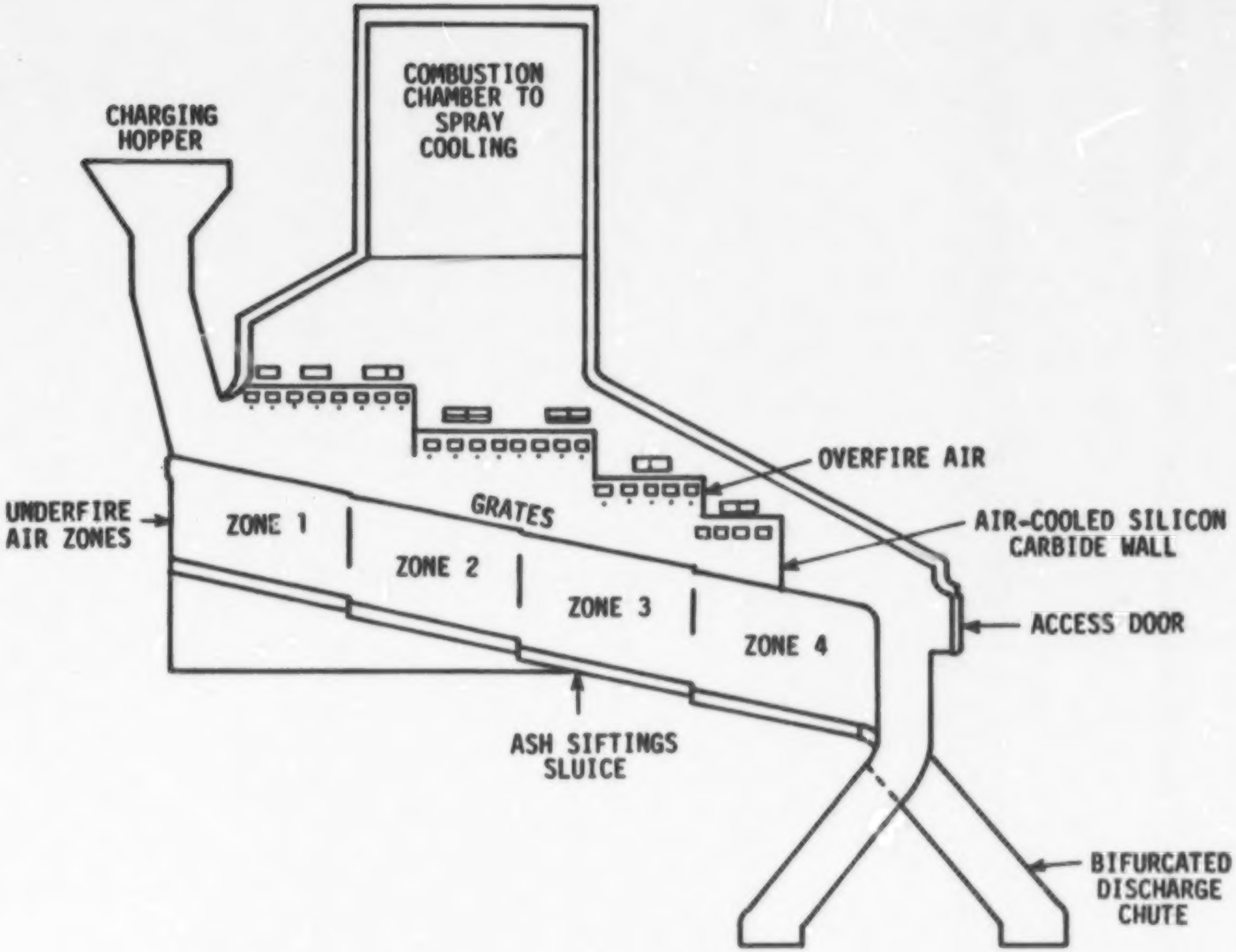

Figure D-2. Example of Municipal Incinerator with no heat recovery.

grates are "zoned" into three to five areas to provide good burning characteristics. Generally, the first stoker zone is not supplied with underfire combustion air. Refractory arches usually are positioned to reflect radiant heat from the combustion process toward the incoming material to dry it and to begin driving off the other volatile, combustible components. Materials are generally brought up to ignition temperature in this first zone, and the burning is not very vigorous.

The highest heat release in the furnace is provided in the next zone or zones. Underfire grate air is supplied to increase the rate of combustion on the grate. Usually 40 to 50 percent of the total air supplied for combustion is supplied to the undergrate air system, and the balance is supplied by overfire air. Many of the better-controlled incinerators supply approximately 100 to 150 percent excess air for combustion, or approximately the stoichiometric requirement of combustion air to the grate. Because most municipal solid wastes are high in volatile material and low in fixed carbon, however, much of the material is volatilized in the active burning zone, and will burn as it leaves the fuel bed or as it enters the secondary combustion zone, where adequate overfire air is provided. Proper mixing is essential in this zone, and the furnace design and placement of the overfire air nozzles are such that it is usually provided.

The last stoker zones provide for carbon burnout and cooling of the ash for later disposal. Depending on the design of the system, a small amount of undergrate air may be directed to these zones; however, some designs do not supply any air to these areas. It is desirable to cool the materials to the extent possible to minimize damage to the ash-handling system and to reduce entrainment of dust as the ash is discharged.

TYPES OF ESP's UTILIZED IN MUNICIPAL INCINERATION APPLICATIONS

The ESP's used in this application typically have been either weighted-wire rigid frame or rigid electrode designs. Generally, they are not large; SCA's of 200 to 300 ft^2/1000 acfm are required to achieve an emission standard of 0.08 gr/dscf, 12 percent CO_2. More stringent emission standards will generally require larger SCA's (i.e., up to approximately 450 ft^2/1000 acfm). These ESP's also tend to only be two fields deep from inlet to

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outlet, although more recent designs may call for three or four fields to improve performance and reliability. In spite of the typically lower SCA, these ESP's are usually designed with a very modest superficial velocity of between 4.0 and 4.5 ft/s with more modern designs in the 3.0 to 3.5 ft/s range. Because these values are on the lower end of the range that may be applied, the reentrainment potential of the ESP is reduced.

OPERATING PROBLEMS THAT AFFECT ESP PERFORMANCE

Wet Fuel

Because of the nature of the fuel, several operating problems are possible that can affect the ESP performance. First, the fuel is usually wet. Depending on the site and time of year, moisture content can vary from 20 to 60 percent by weight. Items such as food wastes, grass and tree clippings, and other wet wastes add to the moisture content of the material. The large quantity of paper products and plastics help offset this problem somewhat. The net effect of the high moisture content is to lower the heat content per pound of material charged. At a fixed charging rate, this in turn lowers the overall heat release rate and the combustion temperature of the furnace. In some locations this situation can be particularly troublesome, e.g., where wet garbage and snow may be mixed together to be burned.

Noncombustible Materials

Another problem is the substantial quantity of noncombustible materials that may be charged to the incinerator; these include cans, other metal materials, large or bulky wooden objects, rocks, dirt, etc. Although paper products and plastics tend to have low ash contents, the overall "ash" content is typically 20 to 30 percent by weight. This ash content also contributes to a lower heating value, and when combined with the moisture effects, heat contents varying from 3000 to 5000 Btu/lb are not unusual. Although typical heat contents range from 3000 to 4000 Btu/lb, in some instances the time/temperature relationship is not sufficient to produce complete combustion.

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Particle Size Distribution

Still another difficulty encountered is the variation in size distribution of fuel that is fed to these incinerators. As with most grate fire systems, good combustion relies on even distribution of properly sized material on the grate. The underfire air will follow the path of least resistance. If the distribution of material on the grate is uneven, the gas will channel through the path of least resistance and the remainder of the fuel bed will be "starved" for air. The underfire air is also required to protect grate components, and failure to supply adequate cooling air can result in premature grate burnout. Items that usually provide the most difficulty are washing machines, hot-water heater tanks, discarded beds, bicycles, large cans, large auto parts, tires, and large wooden items. These items are usually more troublesome for the smaller incinerator than for the large because they affect a larger percentage of the grate area. Because these items also may be difficult to discharge from the incinerator, some operations, such as cogeneration from waste materials, are more selective in their fuel selection and use wastes generated by commercial and small industrial facilities that are dry, free of bulky material, and consist mostly of paper products and plastics.

Incomplete Combustion

If the fuel quality is poor, then combustion may also be poor and result in the generation of partially combusted material because of inadequate time/temperature/turbulence considerations in the combustion zone. Such materials are often high in carbon content, and they tend to condense to form very fine but effective light scattering particles. The high carbon content tends to lower the resistivity, and the finer particles become reentrained; these particles may not be captured because the relatively small ESP's are unable to handle large quantities of fine particles. Under normal circumstances, furnace zone temperatures usually are held to approximately 1400° to 1650°F to provide adequate combustion temperature. The temperature set point is generally maintained by overfire/underfire air ratio and feed rate. Changes in fuel quality affect these requirements, and failure to maintain proper temperature will usually have an adverse effect on ESP performance.

Excess Air

Another area that is important to ESP performance is the quantity of excess air that is carried by the flue gas. Excess air levels of 100 to 150 percent are generally desirable in this application to overcome problems of mixing and to help assure complete combustion. This does not mean that lower excess air quantities cannot be achieved, as some sources are capable of operating at 50 to 75 percent. For those sources using heat recovery, however, care must be taken to control flame impingement and localized reducing zones, which may cause premature tube failure.

Increasing the amount of air in excess of stoichiometric requirements generally improves combustion and raises combustion temperatures. At some point, however, no real increase in combustion efficiency (or conversion to CO_2 and H_2O) results, and increasing the quantity of combustion air actually decreases the flame temperature (because both the combustion products and the excess air must be heated). This can also increase the flue gas volume leaving the incinerator. Even after gases are cooled in an evaporative spray chamber or passed through a heat exchanger, the result is usually a higher gas volume to the ESP, which reduces the actual SCA and treatment time and increases the superficial velocity and the opportunity for more particle reentrainment out of the ESP. Of course, the point of introduction of the excess air will determine how much the excess air will affect combustion efficiency. Careful attention to combustion air settings and to points of inleakage will help minimize problems.

Temperature Effects

The gas stream leaving the incinerator must be cooled before it enters the ESP. Generally, the acceptable temperature range is between 400° and 700°F. Outside of this range, corrosion and other stress-related problems become a concern. The presence of chlorinated plastics, rubber, and other compounds may produce hydrochloric acid. At low temperatures, the acid may condense and attack the metal; at higher temperatures, the corrosive protection afforded by natural inhibitors is substantially reduced. Very often, however, the low temperature acid-dewpoint is of most concern because localized inleakage of air or localized cooling can accelerate the corrosion rate.

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Both of these factors can lead to very rapid destruction of the ESP and other support equipment. Rebuilding of the ESP may be necessary after 3 to 5 years if careful attention is not given to maintaining temperature and providing preventive maintenance.

Evaporative cooling is typically used for incinerators not using heat recovery. A spray baffle system is used to provide contact between the flue gases and water without excessive water droplet carryover. The baffle arrangement also enables the capture of the larger particulate carried out of the incinerator. Use of a temperature sensor/controller is generally recommended to control the amount of evaporative cooling water that is needed.

For those incinerators using heat recovery (typically steam generation), special design considerations are necessary to ensure complete combustion, low slagging and fouling of heat exchange surfaces, and less erosion of boiler tubes. For furnaces equipped with water wall tubes, it is not unusual to have furnace volumes 2 to 3.5 times larger than those used for solid fuels (wood, coal) of equivalent heat release. This increased furnace volume provides longer residence time and an increase in heat absorption before the flue gas enters the convection heat transfer area. Slagging and flame impingement on boiler tubes can cause heat-transfer problems and accelerate corrosion of boiler tubes. These problems can be further aggravated by localized reducing zones in the furnace. Thus, good mixing of sufficient oxygen is important to minimize these problems. Although a higher percentage of excess air will decrease the efficiency of the boiler somewhat, it is usually worthwhile when maintenance considerations are taken into account. Another consideration in furnaces designed for heat recovery is erosion of the refractory and tubes. Generally, the designs call for much lower velocities than would be found in a typical boiler. Special tube designs or arrangements may also be used to minimize tube erosion which can lead to tube failure.

Corrosion Prevention

Use of corrosion resistant materials, proper insulation, prevention of air inleakage, purging acid-laden gas directly after shutdown of the ESP, and use of an indirect heating system during shutdown can extend the life of the ESP from 3 to 5 years to 10 years or better.[1]

Corten or mayari-R have been used in the past instead of mild steel for the ESP shell and collecting electrodes.[1] Although Corten has about twice as much resistance to moisture corrosion as mild steel, it is not significantly more resistant to acid corrosion than mild steel.

Three inches of fiberglass or mineral wool insulation covered by metal lagging should be provided for the casing and hoppers to minimize corrosion. A clean purge air system should be employed to provide clean air to the ESP internals while it is still hot during shutdowns. This will remove free chloride and sulfide ions.

A careful check of the casing should be made during shutdowns to determine if there are any corrosion holes. This may be difficult because of a buildup of dust, which should be removed before inspecting the casing.

To keep the ESP temperature above dewpoint during shutdowns, a small auxiliary heater fired with No. 2 fuel oil can be installed and the heated air blown into the isolated ESP at a temperature of about 350°F. A diagram of such a system is shown in Figure D-3. This type of heating system can also be used to keep the spray tower refractory warm during shutdowns and subsequently minimize thermal shock to the refractory during the succeeding startup.[1]

Another method of keeping the ESP above dewpoint is through the use of a heat-jacket type of shell for the ESP. Warm air is circulated between the double steel casing wall by a small blower. This is similar to the type of shell used on recovery boiler ESP's in the paper industry, and adds about 15 percent to the capital cost of the ESP.[1]

Resistivity Effects

The combination of good combustion and high moisture content in the flue gas, either from moisture in the solid waste or from evaporative cooling, leads to a dust that is relatively easy to collect. Resistivity data for municipal incinerator fly ash is very limited; however, resistivity does not appear to be a substantial problem. Some materials introduced into the incinerators (e.g., dirt and sand) can increase the resistivity of the dust; however, wood and paper products usually produce an ash that is high in alkali content. In ESP applications for wood and bark combustion, resistivity

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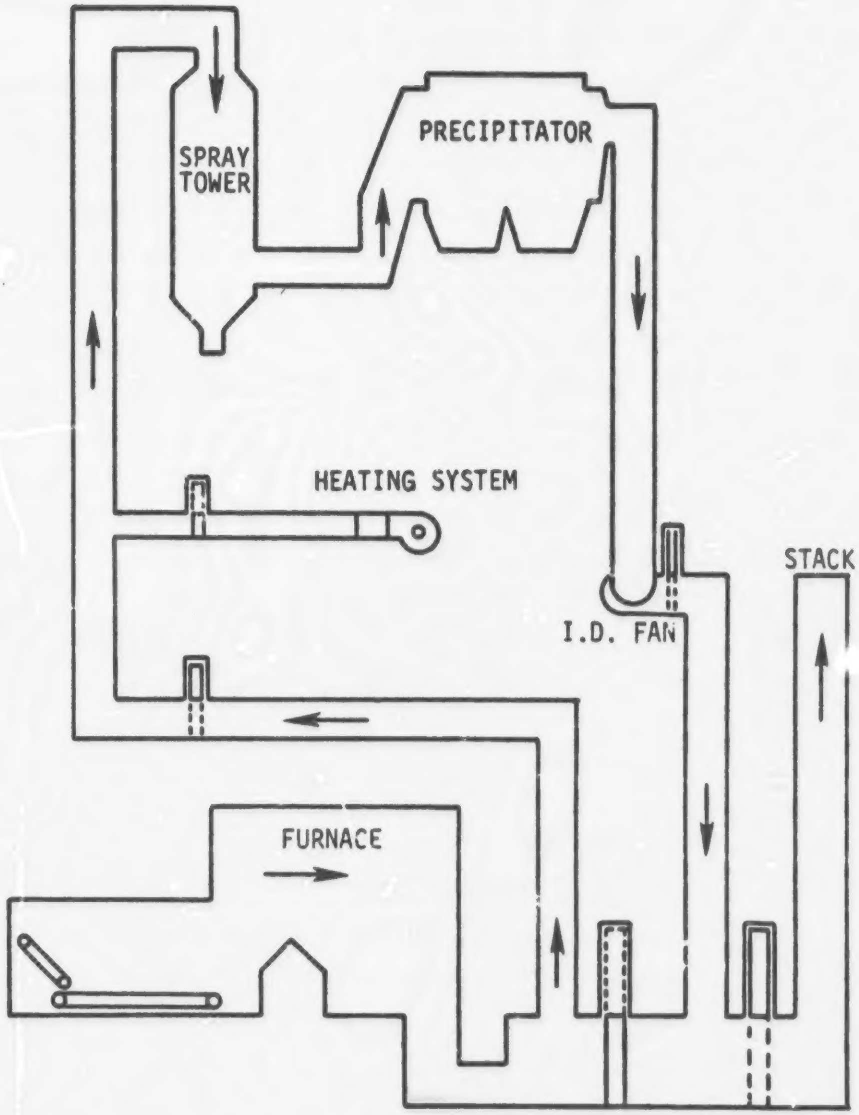

Figure D-3. Location of an auxiliary heating system to keep ESP temperature above the dewpoint.[1]

has been found to be somewhat lower than desirable, but acceptable (10^7 to 10^8 ohm/cm) at typical operating temperature. This condition is expected to apply to firing municipal solid waste as well. From a practical standpoint, operating voltages and currents in these ESP's tend to reflect an acceptable resistivity, as operating voltages and currents are moderately high. For most ESP's in this application, however, low resistivity is probably of greater concern than high resistivity.

Problems with low resistivity appear to worsen when combustion efficiency diminishes or when excess air levels are allowed to become too high. As previously discussed, poor combustion may generate finer particles with higher carbon content. This combination tends to decrease the overall performance of the ESP because it is not generally sized to handle the higher loading of fine particles. In addition, the higher carbon content tends to decrease resistivity and increase reentrainment. Increasing the quantity of flue gas by increasing the excess air may further aggravate the reentrainment problem because the velocity through the ESP is higher. In addition, placing high levels of carbon in ESP hoppers increases the possibility of hopper fires. Maintaining and monitoring good combustion in the furnace is essential to proper ESP operation.

Hopper Pluggage

As in other applications, the hoppers should never be used for long-term storage because the dust flows easily when warm, but not so well when cooled. Continuous removal of the dust not only minimizes the risk of hopper fires, it also tends to reduce the possibility of hopper pluggage that can create a number of other problems (see Section 4). The dust tends to be hygroscopic and, when cooled, can be extremely difficult to remove from the hopper, as it forms clinker-like nodules. Hopper insulation is essential to reduce both hopper pluggage and corrosion problems. In some circumstances, hopper heaters, windbreaks, or enclosures may be necessary to prevent excessive cooling of the dusts.

In conclusion, the application of ESP's to collect the fly ash from municipal incineration does not, in principle, represent a particularly difficult application. Although smaller ESP's have typically been used to handle the lower-resistivity dusts that are expected from this application, newer designs are larger and sectionalized. Some corrosion problems still must be addressed to improve continuous compliance aspects of these ESP's; however, in those installations where adequate monitoring is provided and a conscientious effort is made to maintain good combustion, problems are generally minimal. When the combustion process is not well maintained, however, ESP performance tends to deteriorate noticeably. A good inspection and preventive maintenance program is also essential to minimizing normal operating problems and the potential for corrosion problems in this application.

APPENDIX E

DATA SHEETS AND EXAMPLE CHECKLISTS

PRECIPITATOR CONSOLE DATA SHEET

UNIT: ____________ LOAD ____________

DATE: ____________ OPACITY __________

INLET TEMP. ________

OUTLET TEMP. ________

Legend & Ratings

T.R. No.	
PRI. V	500
PRI. A	128
SEC. KV	45
SEC. mA	1000

Gas ↓ Flow

UPPER BOX

1B2	1B1	1A1	1A2
2B2	2B1	2A1	2A2
3B2	3B1	3A1	3A2
4B2	4B1	4A1	4A2
5B2	5B1	5A1	5A2
6B2	6B1	6A1	6A2
7B2	7B1	7A1	7A2

LOWER BOX

1B2	1B1	1A1	1A2
2B2	2B1	2A1	2A2
3B2	3B1	3A1	3A2
4B2	4B1	4A1	4A2
5B2	5B1	5A1	5A2
6B2	6B1	6A1	6A2
7B2	7B1	7A1	7A2

CORONA ELECTRODE FAILURE AND GROUND REPORT FORM[1]

PLANT - UNIT NO.	DATE: / /	DATA BY:

TR or BUS SECTION NUMBER	SYMPTOM		CAUSE OF GROUND	DESCRIPTION OF GROUND	GRID LOCATION		FAILURE LOCATION (see * below)
	DATE FOUND	TYPE			WIRE LETTER	LANE NO.	

SYMPTOM TYPES	A. Dead Ground - zero voltage, some current, no sparking.
	B. Intermittent Ground - large fluctuation of voltage and current, sparking.
	C. Low Power Operation - Steady state low voltage sparking.

CAUSE OF GROUND	DESCRIPTION
A. Failed corona electrode (wire) touching ground	a1. Penciled break, wire surface away from break smooth (sparking erosion) a2. Flat cross-sectional wire surface away from break smooth (mech. fatigue) a3. Reduced and/or pitted cross-section, wire surface away from break rough (corrosion) a4. Shroud worn through support angle. a5. Wire pulled out of top shroud. a6. Wire pulled out of bottom shroud. a7. Wire from another bus section.
B. Close clearance or contact between high voltage system and ground	b1. Shifted collecting plates. b2. Weight out of guide. b3. Slack wire-weight tilted in guide. b4. Untensioned wire-weight missing. b5. Kinked wire. b6. Bowed collecting plates. b7. Shifted high voltage system.
C. Ash bridge between high voltage system and ground	c1. High hopper flyash level. c2. Clinker between wire and plate. c3. Clinker between shroud and plate. c4. Contaminated insulators.

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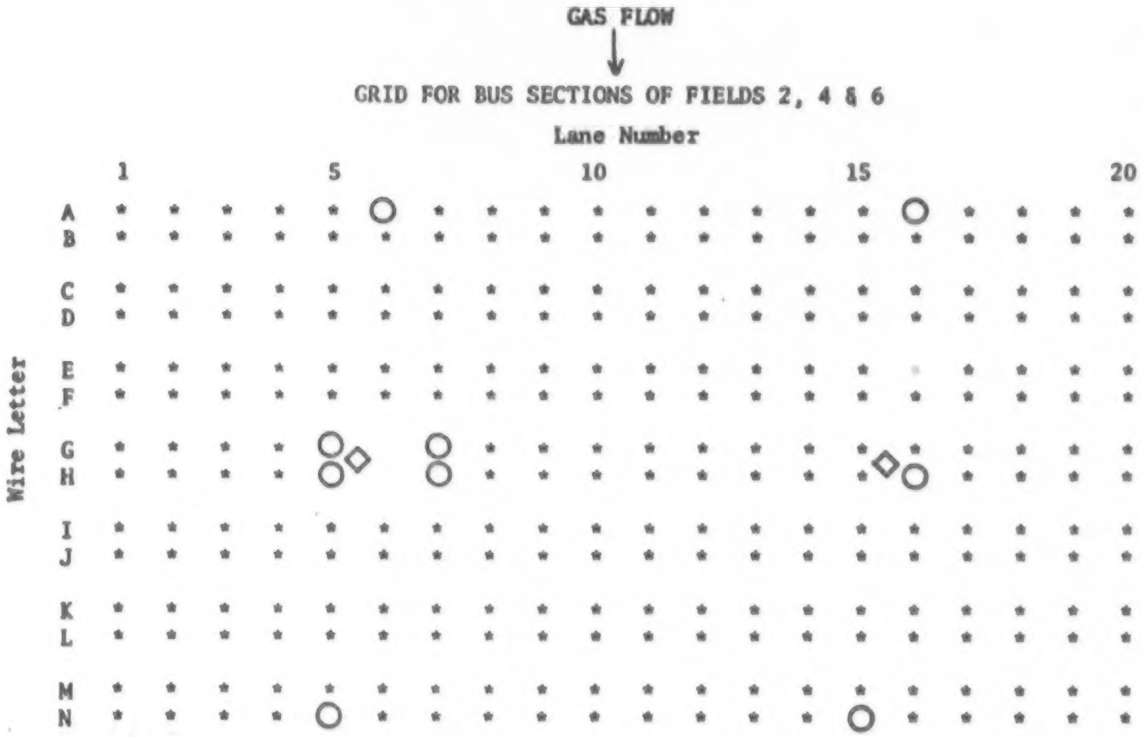
EXAMPLE FORM FOR KEEPING WIRE FAILURE RECORDS.[1]



◇ - SUPPORT/RAPPER ROD
○ - WEIGHT GUIDE FRAME PIPE SUPPORT

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EXAMPLE FORM FOR PRECIPITATOR RAPPER INSPECTIONS[2]

___ AUXILIARY PRECIPITATOR RAPPERS

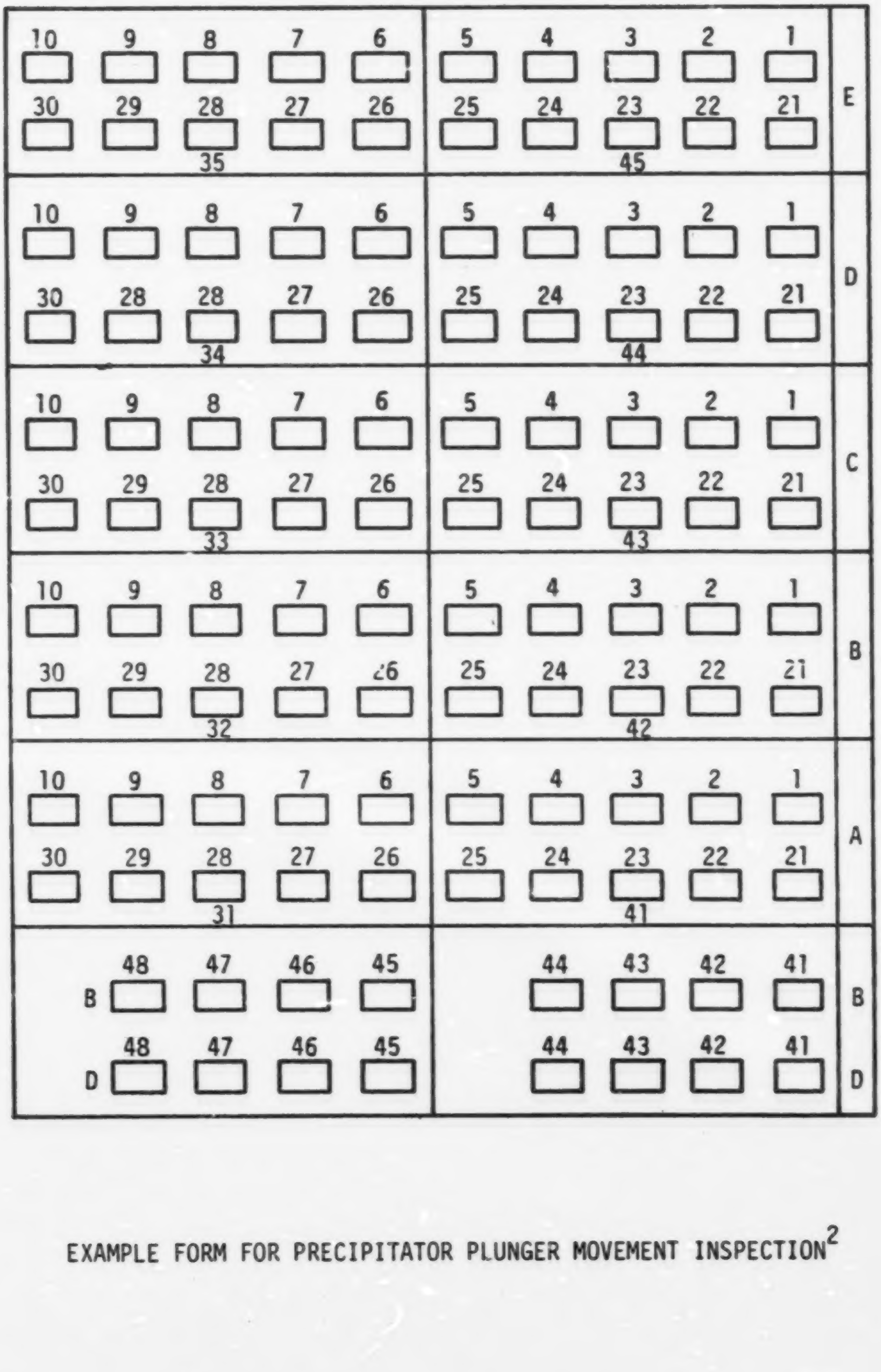
OBSERVER: ____________________

☐ 30 ☐ 29 ☐ 28 ☐ 27 ☐ 26 ☐ 25 ☐ 24 ☐ 23 ☐ 22 ☐ 21	☐ 20 ☐ 19 ☐ 18 ☐ 17 ☐ 16 ☐ 15 ☐ 14 ☐ 13 ☐ 12 ☐ 11	☐ 10 ☐ 9 ☐ 8 ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1	R
24A	34A	44A	
23A	33A	43A	
☐ 30 ☐ 29 ☐ 28 ☐ 27 ☐ 26 ☐ 25 ☐ 24 ☐ 23 ☐ 22 ☐ 21	☐ 20 ☐ 19 ☐ 18 ☐ 17 ☐ 16 ☐ 15 ☐ 14 ☐ 13 ☐ 12 ☐ 11	☐ 10 ☐ 9 ☐ 8 ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1	P
☐ 30 ☐ 29 ☐ 28 ☐ 27 ☐ 26 ☐ 25 ☐ 24 ☐ 23 ☐ 22 ☐ 21	☐ 20 ☐ 19 ☐ 18 ☐ 17 ☐ 16 ☐ 15 ☐ 14 ☐ 13 ☐ 12 ☐ 11	☐ 10 ☐ 9 ☐ 8 ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1	M
22A	32A	42A	
21A	31A	41A	
☐ 30 ☐ 29 ☐ 28 ☐ 27 ☐ 26 ☐ 25 ☐ 24 ☐ 23 ☐ 22 ☐ 21	☐ 20 ☐ 19 ☐ 18 ☐ 17 ☐ 16 ☐ 15 ☐ 14 ☐ 13 ☐ 12 ☐ 11	☐ 10 ☐ 9 ☐ 8 ☐ 7 ☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1	M

1. Loud sound and full plunger movement
2. Paint sound or short plunger movement
3. No sound or plunger movement

↑

GAS FLOW



EXAMPLE FORM FOR PRECIPITATOR PLUNGER MOVEMENT INSPECTION[2]

#38

H	O
☐ ☐ ☐ ☐ 4 3 2 1 25	☐ ☐ ☐ ☐ 4 3 2 1 35
☐ ☐ ☐ ☐ 8 7 6 5 24	☐ ☐ ☐ ☐ 8 7 6 5 34
☐ ☐ ☐ ☐ 12 11 10 9 23	☐ ☐ ☐ ☐ 12 11 10 9 33
☐ ☐ ☐ ☐ 16 15 14 13 22	☐ ☐ ☐ ☐ 16 15 14 13 32
☐ ☐ ☐ ☐ 20 19 18 17 21	☐ ☐ ☐ ☐ 20 19 18 17 31

1. Strong vibration
2. Weak vibration or short time period
3. No vibration

Make a note of any loose or missing bolts, nuts, etc.
Two vibrators in each group operate at the same time (i.e., 1&2, 3&4)

EXAMPLE FORM FOR PRECIPITATOR VIBRATOR INSPECTIONS[2]

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EXAMPLE FORM FOR PRECIPITATOR FLY ASH HOPPER INSPECTION

DATE: ____________________ SHIFT: ______________

TIME: ____________________ ___ FLY ASH HOPPER CHECK

OPERATOR: ________________ SHIFT FOREMAN: ______________ SHIFT ENGR: ________

Hopper no.	Vacuum range		Visual comments	Hopper no.	Vacuum range		Visual comments
	High	Low			High	Low	
1				20			
2				21			
3				22			
4				23			
5				24			
6				25			
7				26			
8				27			
9				28			
10				29			
11				30			
12				31			
13				32			
14				33			
15				34			
16				35			

Month/Year: ______________

EXCESS OPACITY REPORT[2]

Station/Unit(s) ______________

Opacity Limit: 30% (six-minute)

Opacity (%)	Day	Begin*	Cause	Corrective action taken	Initials

* Start time of the six-minute exceedance (24-hour clock).

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ELECTROSTATIC PRECIPITATOR
SHIFT & DAILY OPERATION RECORD[3]

______________ PLANT ______________ UNIT ______________ ESP

DATE: ______________ TIME: ______________ REVIEWED BY/DATE: ______________

GAS TEMP.: A ______ /B ______ OPACITY: A ______ /B ______ GROSS LOAD: ______________

REL. HUMIDITY: ______________ $\%O_2$: ______________ AMB. TEMP.: ______________

T/R CONTROL SET NO.	PRIMARY VOLTS	PRIMARY AMPS	SECONDARY AMPS 1	SECONDARY AMPS 2	SECONDARY KVOLTS 1	SECONDARY KVOLTS 2	SPARKS PER MINUTE	REMARKS

SHIFT CHECKLIST	CHECKED BY (INITIALS)	TIME	CONDITION (CHECK)		NATURE OF DEFICIENCY & CORRECTIVE ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
Transformer-Rectifier Control Meter Readings					
Precipitator Ash Hopper Levels					
Rapper & Vibrator Controller Operation					
DAILY CHECKLIST					
HV Bus Duct Noise					
Localized Sparking					
Precipitator or Boiler Upsets					

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ELECTROSTATIC PRECIPITATOR
WEEKLY EXTERNAL INSPECTION RECORD [3]

______________ PLANT ______________ UNIT ______________ ESP

REVIEWED BY/DATE: ______________________________

INSPECTION ITEM	CHECKED BY (INITIALS)	DATE	CONDITION (CHECK)		NATURE OF DEFICIENCY & CORRECTION ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
Check HV Transformer Oil Level & Temp.					
Inspect T/R Control & Purge Air Filters					
Check Access Door Air Inleakage					
Check Purge Air & Heater System Operation					
Rapper System Settings Check					
Vibrator System Settings Check					

Weekly Average As Fired Fuel Analysis: % Moisture ______________________________

% Ash ______________________________

% Sulfur ______________________________

BTU/LB ______________________________

Rapper/Vibrator Setting Record	BY (INITIALS)	DATE	FIELD 1	FIELD 2	FIELD 3	FIELD 4	REMARKS
Rapper Settings-Previous Intensity Frequency							
Rapper Settings-New Intensity Frequency							
Vibrator Settings-Previous Intensity Frequency							
Vibrator Settings-New Intensity Frequency							

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ELECTROSTATIC PRECIPITATOR
QUARTERLY EXTERNAL INSPECTION RECORD[3]

_____________PLANT _____________UNIT _____________ESP

REVIEWED BY/DATE: ______________________________

INSPECTION ITEM	BY (INITIALS)	DATE	CONDITION (CHECK)		NATURE OF DEFICIENCY & CORRECTIVE ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
Clean Rapper, Vibrator, T/R Controls					
Rapper Switch Contact Inspection					
Vibrator Switch Contact Inspection					
Check Rapper Assembly Binding/ Misalignment					
Rapper/Vibrator Boot Seals Inspection					
Rapper Plunger Condition Inspection					
Check for Defective Rappers					
Check for Defective Vibrators					
Check Vibrator Air Gap Setting					
Check Instrument Calibration					

ELECTROSTATIC PRECIPITATOR
ANNUAL INTERNAL INSPECTION RECORD[3]

______________PLANT ______________UNIT ______________ESP

INSPECTION ITEM	BY (INITIALS)	DATE	CONDITION		NATURE OF DEFICIENCY & CORRECTIVE ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
A. Transformer Enclosure:					
Clean and Check Insulators, Bushings					
Check Electrical Connections					
Check and Set Surge Arrestors					
B. HV Bus Duct:					
Inspect for Rust or Scaling					
Clean and Check Post Insulators					
Check for Loose Connections					

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INSPECTION ITEM	BY (INITIALS)	DATE	CONDITION		NATURE OF DEFICIENCY & CORRECTIVE ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
Repair Loose Bus Elbows					
C. Penthouse, Rappers, Vibrators:					
Check Centering of Upper Rapper Rod					
Clean and Check Rapper Insulators					
Inspect for Ash Accumulations Around Rods					
Check Centering of Lower Rapper Road					
Check Insulator Heater					
Check for Water/Air Leakage in Penthouse					
Inspect Roof Penetrations for Water Leakage					
Check All HV Connections					
Clean and Check Support Insulators					
Check Collars on Vibrator Insulators					
D. Collecting Surface Anvil Beam:					

EST COPY AVAILABLE

INSPECTION ITEM	BY (INITIALS)	DATE	CONDITION		NATURE OF DEFICIENCY & CORRECTIVE ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
Inspect Hanger Rods and Clips					
Remove Packed Ash Behind Anvil Beam					
Inspect Welds of Rods to Anvil Beam					
E. Upper HT Frame Assembly:					
Inspect Welds at Hanger Pipe to Frame					
Check HT Frame Support Bolts					
Inspect Welds at Support Angles to Beam					
Check Level and Square of Frame					
F. Lower HT Frame Assembly					
Check Weight-Guide Rings & Align					
Check Level and Square of Frame					
Check Lower Frame Twisting					
G. Stabilization Insulators:					

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INSPECTION ITEM	BY (INITIALS)	DATE	CONDITION		NATURE OF DEFICIENCY & CORRECTIVE ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
Clean and Check Insulators					
H. Collecting Electrodes:					
Check Ash Buildups					
Check Electrode Alignment & Spacing					
Check Plumb and Square of Components					
Inspect for Bowing or Bellying					
I. Discharge Electrode Assembly:					
Check Ash Buildups					
Check for Broken Electrodes					
Check Alignment and Spacing					
Check Weights for Alignment & Freedom					
J. Hopper Inspection					
Check for Ash Buildup in Upper Corners					

INSPECTION ITEM	BY (INITIALS)	DATE	CONDITION		NATURE OF DEFICIENCY & CORRECTIVE ACTION TAKEN
			ACCEPTABLE	UNACCEPTABLE	
Check for Debris in Bottom and Valve					
Check Hopper Level Detectors					
Check Hopper Vibrators					
K. General:					
Inspect for Interior Corrosion					
Check Safety-Key Interlocks					
Inspect Electrical Grounding System					
Check Thermal Expansion if Required					
Check for Ash Buildup on Vanes, Ducts					
Check Transformer Oil Dieletric					

REVIEWED BY:

Electrical Foreman: ______________________ Date: __________

Mechanical Foreman: ______________________ Date: __________

Maintenance Supervisor: ______________________ Date: __________

Operating Supervisor: ______________________ Date: __________

Administrative Supervisor: ______________________ Date: __________

Plant Manager: ______________________ Date: __________

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ESP BASELINE TEST INFORMATION

A. Process Conditions

Gas flow rate
Gas temperature - points A,B,C, etc.
Static pressure
Process level (load, % capacity)
Process feed rate(s)
Process feed descriptor(s)
Process product level(s)
Process product descriptor(s)
Conditioning agents (type and ppm)

B. ESP Operating Conditions

Gas temperature, ESP inlet(s)
Gas temperature, ESP outlet(s)
Primary voltage for each field
Primary current for each field
Secondary voltage for each field
Secondary current for each field
Spark rate for each field
Rapper frequency, plate
Rapper frequency, wire
Rapper duration, plate
Rapper duration, wire
Rapper intensity

C. Stack Test Results

Testing crew, group leader, date
Outlet particulate concentration, average
Outlet particulate concentration, individual runs
Inlet particulate concentration, average
Inlet particulate concentration, individual runs
Sampling times per run
Sampled gas volumes per run
Gas composition
Moisture content
Emission level, lb/h
Emission level, lb/process input parameter
Emission level, lb/process output parameter
Effluent opacity (including presence or absence of puffing)

D. Applicable Regulations

Particulate
SO_2
Opacity

ELECTROSTATIC PRECIPITATOR BASELINE COMPARISON

Possible operating problems	Average baseline (specify value)	Observed (specify value)	Location[a]	Abnormal (check)
I. ELECTRICAL				
A. Particle resistivity				
1. Peak voltage low (down 5-10 kV)			E	
2. Rapping intensity (increased)			E	
3. Temp changed (±50°F)			E	
4. Spark rate increased (±50 sparks/min)			E	
5. Opacity high			E	
6. Coal sulfur content low (<1.0%)			E	
B. Transformer-rectifier set problems				
1. No secondary current	N/A	N/A	E	
2. No penthouse purge	N/A	N/A	E	
3. Voltage zero, current high	N/A	N/A	E	
4. Opacity high			E	
C. Insulator failure				
1. Peak voltage low			E	
2. Penthouse purge (not used)	N/A	N/A	E	
3. Penthouse temp high (±20°F)			E	
4. Opacity high			E	
5. Cracks visible	N/A	N/A	I	

[a] E is external, I is internal.

ELECTROSTATIC PRECIPITATOR BASELINE COMPARISON (continued)

Possible operating problems	Average baseline (specify value)	Observed (specify value)	Location[a]	Abnormal (check)
I. ELECTRICAL (continued)				
D. Broken discharge wires				
1. Deposits on wires	N/A	N/A	I	
2. Violent meter fluctuating	N/A	N/A	E	
3. Hopper level indicator not used	N/A	N/A	E	
4. Spark rate high (±50 sparks/min)			E	
5. Opacity high			E	
6. Broken discharge wires	N/A	N/A	I	
II. GAS FLOW				
A. Excessive velocity				
1. Flow rate high			E	
2. Voltages high, currents low			E	
3. Opacity high			E	
B. Nonuniform distribution				
1. Flow rate increased			E	
2. Secondary currents nonparallel	N/A	N/A	E	
3. Hopper level differences on parallel branches			I	
4. Rappers on distribution plates not used			E or I	

---

[a] E is external, I is internal.

ELECTROSTATIC PRECIPITATOR BASELINE COMPARISON (continued)

Possible operating problems	Average baseline (specify value)	Observed (specify value)	Location[a]	Abnormal (check)
III. MECHANICAL				
A. Rapper problems				
1. Puffs visible	N/A	N/A	E	
2. Peak voltage changes, secondary current constant			E	
3. Spark rate changed			E	
4. Low sulfur coal used			E	
5. Dust sticky	N/A	N/A	E	
B. Hopper solids removal				
1. Broken discharge wires	N/A	N/A	I	
2. Mass loading probably increased	N/A	N/A	E	
3. Nonuniform gas distribution	N/A	N/A	E	
4. Hoppers not emptied continuously	N/A	N/A	E	
5. Level indicators not used	N/A	N/A	E	
6. Heaters not used	N/A	N/A	E	
7. Vibrators not used	N/A	N/A	E	
8. Hoppers not insulated	N/A	N/A	E	
9. Corrosion around outlet valves	N/A	N/A	I	
10. Hopper slope <60°	N/A	N/A	E	
11. Hoppers full or bridged	N/A	N/A	I	
C. Collection plate warpage and malalignment				
1. Change in air load	N/A	N/A	E	
2. Repeated hopper overflow	N/A	N/A	E or I	
3. Air inleakage	N/A	N/A	E	
4. Malalignment visible	N/A	N/A	I	

[a] E is external, I is internal.

ELECTROSTATIC PRECIPITATOR BASELINE COMPARISON (continued)

Possible operating problems	Average baseline (specify value)	Observed (specify value)	Location[a]	Abnormal (check)
IV. EFFLUENT CHARACTERISTICS				
A. Mass loading increases				
1. Opacity high			E	
2. Inlet section, secondary currents, low			E	
3. Hopper unloading frequency increased			E	

---

[a] E is external, I is internal.

AIR LOAD TEST RECORD[3]

______ PLANT ______ UNIT

TIME: ______

REVIEWED BY: ______

DATE: ______

TESTED BY: ______

ESP: ______

T/R SET NO.: ______

FIELD ENERGIZED: ______

ESP TEMP.: ______

AMBIENT TEMP.: ______

WEATHER COND.: ______

CONTROL	TRANSFORMER PRIMARY		PRECIPITATOR					REMARKS
MANUAL	AMPS	VOLTS	MILLIAMPS		S/M	KV1	KV2	
			1	2				
AUTOMATIC								

S/M: Sparks/Minute

KV1: Kilovolts/Bushing 1

EXAMPLE BID EVALUATION FORMS FOR ELECTROSTATIC PRECIPITATORS

BID EVALUATION FORM FOR ELECTROSTATIC PRECIPITATORS[4]

	Bidder #1	Bidder #2	Bidder #3	Bidder #4
PRECIPITATOR VENDOR				
OPERATING AND PERFORMANCE DATA:				
Volume — CFM @ operating conditions				
Temperature — °F @ operating conditions				
Inlet loading — grains/cf @ operating conditions				
Dust Bulk Density				
Guaranteed Efficiency — Percent				
Guaranteed Outlet Loading — gr./act. cu. ft.				
Pressure Drop Across Precipitator including gas distribution devices				
Gas Velocity — ft./sec.				
Treatment Time-Seconds				
PRECIPITATOR ARRANGEMENT				
Number of Precipitators				
Chambers (number) /Precipitator				
Fields (number and length) /Precipitator				
Cells (number) /Precipitator				
Bus sections (number) /Precipitator				
Casing Material and Thickness (inches)				
Casing Design Pressure (" W.C.) (Check one: Positive ☐ or Negative ☐)				
Number of Hoppers/Precipitator				
Hopper Material and Thickness (inches)				
Minimum Hopper Valley Angle				
Total Hopper Capacity (cubic feet)/Precipitator				
Hopper Accessories (list each separately)				
Insulator Compartment Material and Thickness (inches)				
Penthouse Material and Thickness (inches)				
Number of Insulator Compartments/Precipitator				
Surface Area (sq. ft.)/Precipitator				
Roof				
Shell				
Hoppers				
Other				

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BID EVALUATION FORM (continued)

	Bidder #1	Bidder #2	Bidder #3	Bidder #4
Precipitator Internal Gas Distribution Devices				
Types				
Quantity and Location Precipitator				
Material and Thickness				
Number and Type Rappers				
Number, Type and Size of Access Doors Precipitator				
Roof				
Shell				
Hopper				
Insulator Compartments				
Other				
COLLECTING SYSTEM — PER PRECIPITATOR				
Number of Gas Passages				
Spacing of Gas Passages (inches)				
Collecting Surface Material and Thickness				
Collecting Surface Effective Length (feet)				
Collecting Surface Effective Height (feet)				
Total Collecting Surface Area				
Maximum Collecting Surface Area Rapped at any Instant (square feet)				
Type Collecting Surface Rappers				
Number of Collecting Surface Rappers per Precipitator				
HIGH VOLTAGE SYSTEM				
Discharge Electrode — Type, Material and Thickness (inches)				
Total Lineal Feet of Effective Discharge Electrode per Precipitator				
Type Discharge Electrode Rappers				
Total Number of Discharge Electrode Rappers per Precipitator				
HIGH VOLTAGE ELECTRICAL SET				
Type Transformer Rectifier				
Number Transformer Rectifiers				
Size Transformer Rectifier				
Voltage Rating KV (DC) Avg (For pure resistive loads)				
Current Rating Milliamps (DC) Avg (For pure resistive loads)				
Number of Transformer Rectifier Control Cabinets				
Construction of Transformer Rectifier Control Cabinets NEMA				

BID EVALUATION FORM (continued)

	Bidder #1	Bidder #2	Bidder #3	Bidder #4
Transformer Rectifier Insulation Fluid				
Wave Form of High Voltage				
Number and Type High Voltage Switches				
Key Interlocks (Yes — No)				
Control Cabinets				
Transformer Rectifiers				
Access Doors				
Type Transformer Rectifier Controls				
Maximum Ambient Temperature for Transformer Rectifier — °C				
Maximum Ambient Temperature for Transformer Rectifier Control Cabinets — °C				
Power Consumption KVA Precipitator				
1. Transformer-rectifier				
2. Rappers				
3. Insulator heaters and blowers				
4. Hopper heaters				
5. Lights				
6. Other				
Total				
Total connected load KVA Precipitator				
Power Distribution				
Individual breakers each control cabinet				
Central distribution panel				
OTHER AUXILIARY EQUIPMENT OR SERVICES				
Heat Insulation — Type & Thickness				
Weather Enclosure — (Roof and/or Hopper, type)				
Inlet and outlet Transitions — Material and Thickness				
Access Facilities — Type & Location				
Insulator Compartment Blower System (number)				
Model Study				
Startup—Training—Testing Supervision				
Erection Supervision				
WEIGHTS				
Total Precipitator Weight Including Electrical Equipment but Excluding Dust Load				

BIDDING DATA LIST
FOR
ELECTROSTATIC PRECIPITATORS[5]

DATE PURCHASER'S INQUIRY NUMBER

Section A.

General Information

1) Purchaser Address
   - a) User (if different from above)
     Address
2) Site Location
3) Individual, title and address to whom proposal is to be sent.
   - a) Number of copies of proposal to
4) Date proposal is to be submitted
5) Purpose of proposal: budgetary or firm?
6) Is formal proposal required, or priced letter?
7) Equipment delivery requirement date
8) Bid Basis: FOB shipping point; FOB cars destination; FOB shipping point FA to site; other

Section B.

Plant Process

1) Process to which precipitator will be applied

   Furnace, boiler, kiln, other

   Design data: Type

   Make

   Output: continuous rating

   peak rating
2) Description and analyses of raw material or fuel
3) Expected variations in raw material input to furnace, etc.

4) Description and rating of existing collector equipment, if any ______________________________

____

Section C.

Operating Conditions

1) Gas volume at precipitator inlet as measured by Pitot tube:

@ Continuous rating, actual cfm __________ @ __________ °F., __________ psia.

@ Peak rating, actual cfm __________ @ __________ °F., __________ psia.

Moisture content in gas % by volume __________ or % by weight __________

Volume for which precipitator efficiency guarantee is to be based, continuous or peak __________

____

2) Gas analysis, Orsat or calculated ______________________________

3) Chemical analysis of dust or liquid to be collected; include specific gravity, bulk density of dust with two values, one for volumetric capacity of dust hoppers and the other for structural design.

____

____

a) Is a representative sample of dust available? (yes) __________

(no) __________

4) Particle size analysis ______________________________

____

5) Dust load at precipitator inlet:

@ Continuous rating, actual grains/cubic foot ______________________________

@ Peak rating, actual grains/cubic foot ______________________________

Conditions on which precipitator performance guarantee is to be based, continuous or peak __________

____

6) Barometric pressure or elevation at plant site ______________________________

Section D.

Performance

1) Collection efficiency __________%.

Section E.

Layout Drawings

1) The precipitator will be installed generally in conformance with the attached drawing number __________.

2) Maximum permissible pressure drop through equipment being supplied by bidder: - inches W.C. __________.

3) Indicate single or multiple chamber requirement ______________________________.

Section F.

Design Features

The precipitator will have the following structural design features:

1) Operating pressure __________ W.C. Negative - Positive.

2) Design pressure ____________ W.C. Negative - Positive.

3) Design temperature ____________ °F.

4) Casing material ______________________________ ; Thickness ______________________________

5) Hopper material ______________________________ ; Thickness ______________________________

6) Minimum hopper valley angle ____________ ° from horizontal.

7) Type of bottom: hoppers (pyramidal, bunker) drag scraper,
wet ______________________________

Specify storage capacity ______________ hours.

Section G.

Auxiliary Equipment By	Purchaser	Bidder	Description
Supporting steel			
Access facilities			
Transition nozzles			
Ductwork & expansion joints			
Gates & dampers			
Hopper dust valves & conveyors			
Control room			
Instrumentation			
Fans & auxiliaries			
Motor control center			
Other			

Section H.

Erection Scope

1) Erection By: purchaser or bidder ______________________________

2) Erection supervisor services; separate quote or include in material price ______________

3) Start up and test engineer services; separate quote or include in equipment price ______________
____

4) Travel and subsistence costs for erection forces by purchaser or bidder ______________

5) Erection period: Starting date ______________ Completion date ______________

6) Site information:

Storage area; size in sq. ft. and distance from job site ______________________________
____

Availability of closed storage area ______________________________

Freedom of crane area ______________________________

Overhead obstacles ______________________________

Distance utility sources are from job site ______________________________

Is truck roadway and/or railroad right-of-way to storage area ____________ ; to job site ____________ ,
if not, distance from unloading point to storage area ______________________________ .

7) Scope of erection responsibility:	Purchaser	Bidder
Foundations (piles or slabs)		
Material unloading to storage		
Material rehandling to job site		
Low voltage wiring		
Insulation (type, etc.)		
Ductwork, gates, expansion joints, etc.		
Lighting		
Erection equipment: cranes, welding machines, etc.		
Erection facilities: field office, change shanty & sanitary facilities		
Erection utilities: air, water, light		
Field painting: (complete or touch-up)		
Electrical substation		

Attach description of above items if not covered by plant standards.

8) Available electric power

For Precipitator ________ Volts, ________ Phase, ________ Cycle, ________ KVA

For Erection ________ Volts, ________ Phase, ________ Cycle, ________ KVA

For Controls & Instrumentation ________ Volts, ________ Phase, ________ Cycle, ________ KVA

9) Plant standards attached ____________________

10) Other remarks or comments ____________________

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1. Ahern, A. J. A Coordinated Approach By a Central Group to Maintain Precipitator Compliance. Presented at APCA Specialty Conference on Operation and Maintenance Procedures For Gas Cleaning Equipment. Sponsored by IGCI and EEI. Pittsburgh, Pa. April 1980.

2. Commonwealth Edison Company. Particulate Emissions Compliance Procedures.

3. Carolina Power and Light Company. Operation and Maintenance Manual For Electrostatic Precipitators. February 1981.

4. Industrial Gas Cleaning Institute, Inc. Bid Evaluation Form for Electrostatic Precipitators. Publication No. E-P4, January 1968.

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GLOSSARY OF TERMINOLOGY

TERMINOLOGY FOR ELECTROSTATIC PRECIPITATORS[1]

I. ENVELOPING STRUCTURE

A. Casing

1. For Rectangular Configuration

- a. Gastight roof
- b. Side Wall
- c. End Wall
- d. Hoppers and or bottoms
- e. Gas inlet
- f. Gas outlet
- g. Dividing wall (gastight)
- h. Load bearing wall (non-gastight)
- i. External roof (non-gastight)

2. For Cylindrical Configuration

- a. Gas inlet
- b. Gas outlet
- c. Hoppers and or bottom
- d. Head
- e. Shell

B. Auxiliary Items

1. Insulator Compartment - Enclosure for the insulator(s) supporting the high voltage system (may contain one or more insulators, but not enclosing the roof as a whole).

2. Enclosures

- a. Penthouse - A weatherproof, gas-tight enclosure over the precipitator to contain the high voltage insulators.

- b. Upper Weather Enclosure - A non gas-tight enclosure on the roof of the precipitator to shelter equipment (T/R sets, rappers, purge air fans, etc.) and maintenance personnel.

- c. Lower Weather Enclosure - A non gas-tight enclosure at base of precipitators to protect hoppers from wind and/or detrimental weather conditions.

3. Access Means

- a. Doors - A hinged or detached cover provided with a hand operated fastening device where accessibility is required.

- b. Bolted Plate - A cover provided with sufficient bolts to insure tight closure where occasional accessibility is required.

4. Dampers

- a. Control - A device installed in a duct to regulate the gas flow by degree of closure; examples: Butterfly or Multi-Louver.
- b. Isolation - A device installed in a duct to isolate a precipitator chamber from process gas

5. Safety Grounding Device - A device for physically grounding the high voltage system prior to personnel entering the precipitator. (The most common type consists of a conductor, one end of which is grounded to the casing, the other and attached to the high voltage system using an insulated operating lever).

6. Transition - An aerodynamically designed inlet or outlet duct connection to the precipitator. Transitions are normally included as part of the precipitator.

7. Gas Distribution Devices - Internal elements in the transition or ductwork to produce the desired velocity contour at the inlet and outlet face of the precipitator; example: turning vanes or perforated plates

- a. Anti-sneakage baffles - Internal baffle elements within the precipitator to prevent the gas from bypassing the active field or causing hopper re-intrainment.

- b. Turning vanes - Vanes in ductwork or transition to guide the gas and dust flow through the ductwork in order to minimize pressure drop and to control the velocity and dust concentration contours.

- c. Gas distribution plate rapper - A device used to prevent dust buildup on perforated plates.

II. COLLECTING SYSTEM

The grounded portion of the precipitator to which the charged dust particles are driven and to which they adhere:

A. Collecting Surfaces

The individual elements which make up the collecting system and which collectively provide the total surface area of the precipitator for the deposition of dust particles.

B. Collecting Surface Rapper

A device for imparting vibration or shock to the collecting surface to dislodge the deposited particles or dust.

III. HIGH VOLTAGE SYSTEM

All parts of the precipitator which are maintained at a high electrical potential.

A. High Voltage Structure

The structural elements necessary to support the discharge electrodes in their relation to the collecting surface by means of high voltage insulators.

B. Discharge Electrode

The part which is installed in the high voltage system to perform the function of ionizing the gas and creating the electric field. Typical configurations (see sketch) are:
Rigid Frame
Weighted Wire
Rigid Discharge Electrode

C. Discharge Electrode Rapper

A device for imparting vibration or shock to the discharge electrodes in order to dislodge dust accumulation.

D. High Voltage System Support Insulator

A device to physically support and electrically isolate the high voltage system from ground.

E. Rapper Insulator

A device to electrically isolate discharge electrode rappers yet transmit mechanically, forces necessary to create vibration or shock in the high voltage system.

IV. PRECIPITATOR ARRANGEMENTS

A. Precipitator

A single precipitator is an arrangement of collecting surfaces and discharge electrodes contained within one independent casing

B. Bus Section

The smallest portion of the precipitator which can be independently de-energized (by sub-division of the high voltage system and arrangement of support insulators.)

C. Field (In Depth)

A field is an arrangement of bus sections perpendicular to gas flow, that is energized by one or more high voltage power supplies.

D. Cell (In Width)

A cell is an arrangement of bus sections parallel to gas flow.

Note: Number of cells wide times number of fields deep equals the total number of bus sections.

E. Chamber

A gastight longitudinal subdivision of a precipitator. A precipitator with a single gastight dividing wall is referred to as a two chamber precipitator.

Note: Very wide precipitator chambers are frequently equipped with non-gastight load bearing walls for structural considerations. These precipitators by definition are single chamber precipitators.

V. ELECTRICAL TERMS

A. High Voltage Power Supply

The supply unit to produce the high voltage required for precipitation, consisting of a transformer-rectifier combination and associated controls. Numerous bus sections can be independently energized by one power supply.

1. Transformer-Rectifiers

A unit comprising a transformer for stepping up normal service voltages to voltages in the kilovolt range, and a rectifier operating at high voltage to convert AC to unidirectional current.

a. Types of Rectifiers

1. Silicon Rectifier

A rectifier consisting of silicon diodes immersed in mineral oil or silicone oil

2. Other

Older precipitator installations may be equipped with electronic tube or selenium rectifiers, however these types are obsolete today.

B. Impedance Devices

1. Linear inductor or current limiting reactor required to work with SCR-type controllers.

2. A transformer with a specially designed high impedance core and coils.

3. Saturable core reactor.

4. Resistors.

C. Control Equipment - Consists Mainly Of:

a. High Voltage Power Supply Control Equipment

Electrical components required to protect, monitor, and regulate the power supplied to the precipitator high

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voltage system. Regulating the primary voltage of the high voltage transformer-rectifier is accomplished by one of the following devices:

1. Saturable Core Reactor

   A variable impedance device.

2. Variable "Auto-Transformer" control.

3. Silicon-Controlled Rectifier (SCR) - Electronic switch for voltage regulation.

   The above can be:

   1. Automatic power supply control - Automatic regulation of high voltage power for changes in precipitator operating conditions utilizing feed back signal(s).

   2. Manual Power Supply Control - Manual regulation of high voltage power based on precipitator operating conditions as observed by plant operators.

b. Auxiliary Control Equipment

Electrical components required to protect, monitor, and control the operation of precipitator rappers, heaters, and other associated equipment.

D. High Voltage Conductors

Conductor to transmit the high voltage from the transformer-rectifier to the precipitator high voltage system.

1. H.V. Bus

   A conductor enclosed within a grounded duct.

2. Cable

   a. Oil-filled cable
   b. Dry cable

E. General Terms

1. Primary Current

   Current in the transformer primary as measured by an AC ammeter.

2. Primary Voltage

   The voltage as indicated by AC voltmeter across the primary of the transformer.

3. Precipitator Current

   The rectified or unidirectional average current to the precipator measured by a milliameter in the ground leg of the rectifier.

4. Precipitator Voltage

   The average DC voltage between the high voltage system and grounded side of the precipitator.

5. Spark

   A discharge from the high voltage system to the grounded system, self-extinguishing and of short duration.

6. Arc

   A discharge of substantial magnitude of the high voltage system to the grounded system, of relatively long duration and not tending to be immediately self-extinguishing.

VI. GENERAL TERMS

A. Dust or Mist Concentration

The weight of dust or mist contained in a unit of gas, e.g pounds per thousand pounds of gas, grains per actual cubic foot of gas, or grains per standard dry cubic foot (the temperature and pressure of the gas must be specified if given as volume).

B. Collection Efficiency

The weight of dust collected per unit time divided by the weight of dust entering the precipitator during the same unit time expressed in percentage. The computation is as follows:

$$\text{Efficiency} = \frac{(\text{Dust in}) - (\text{Dust out})}{(\text{Dust in})} \times 100$$

C. Precipitator Dimensions

1. Effective Length
   Total length of collecting surface measured in the direction of gas flow. Length between fields is to be excluded.

2. Effective Height
   Total height of collecting surface measured from top to bottom.

3. Effective Width
   Total number of gas passages multiplied by spacing dimension of the collecting surfaces.

4. Effective Cross-Sectional Area
   Effective width times effective height.

D. Precipitator Gas Velocity

A figure obtained by dividing the volume rate of gas flow through the precipitator by the effective cross-sectional area of the precipitator. Gas velocity is generally expressed in terms of ft./sec. and is computed as follows:

$$\text{Velocity} = \frac{\text{Gas Volume (Ft.}^3\text{/sec.)}}{\text{Effective cross-section area (Ft.}^2\text{)}}$$

Effective cross-section is construed to be the effective field height X width of gas passage X number of passages.

E. Treatment Time

A figure, in seconds, obtained by dividing the effective length, in feet, of a precipitator by the precipitator gas velocity figure calculated above.

F. Aspect Ratio

The ratio obtained by dividing effective length of the precipitator by the effective height.

G. Collecting Surface Area

The total flat projected area of collecting surface exposed to the active electrical field (effective length x effective height x 2 x number of gas passages).

H. Specific Collecting Area (SCA)

A figure obtained by dividing total effective collecting surface of the precipitator by gas volume, expressed in thousands of actual cubic feet per minute.

I. Migration Velocity

A parameter in the Deutch-Anderson equation used to determine the required size of an electrostatic precipitator to meet specified design conditions. Other terminology are W-value and precipitation rate. Values are generally stated in terms of ft./min. or cm/sec.

J. Current Density

The amount of secondary current per unit of ESP collecting surface. Common units are ma/ft.^{2} and nA/cm^2.

K. Corona Power (KW)

The product of secondary current and secondary voltage.

Power density is generally expressed in terms of: (1) watts per square foot of collecting surface, or (2) watts per 1000 ACFM of gas flow.

L. Rapping Intensity

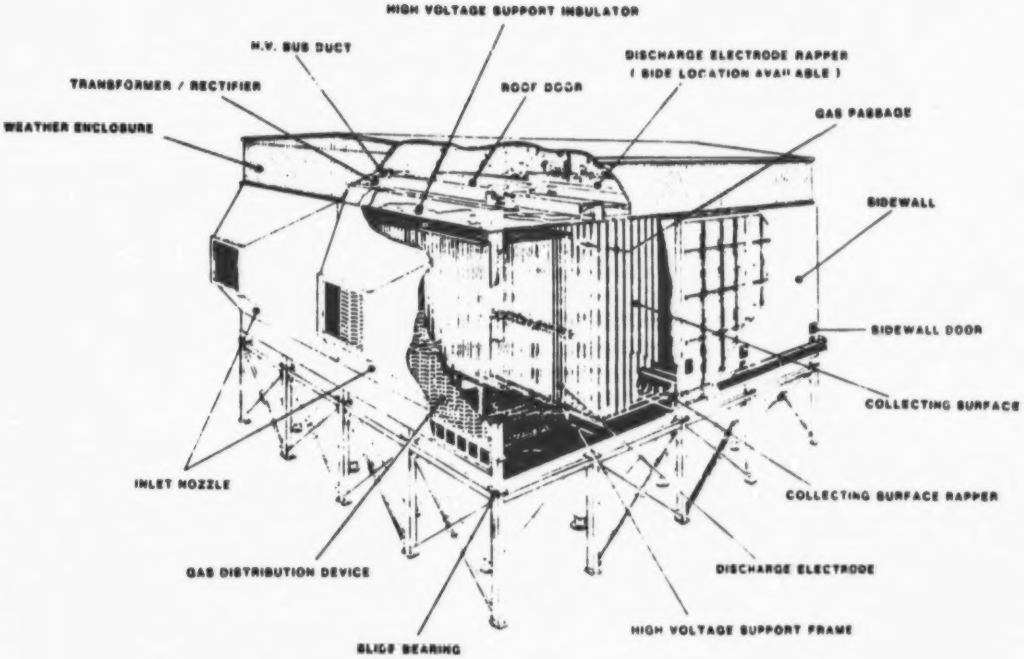
The "g" force measured at various points on collecting or discharge electrodes. Measured forces should be specified as longitudinal or transverse.

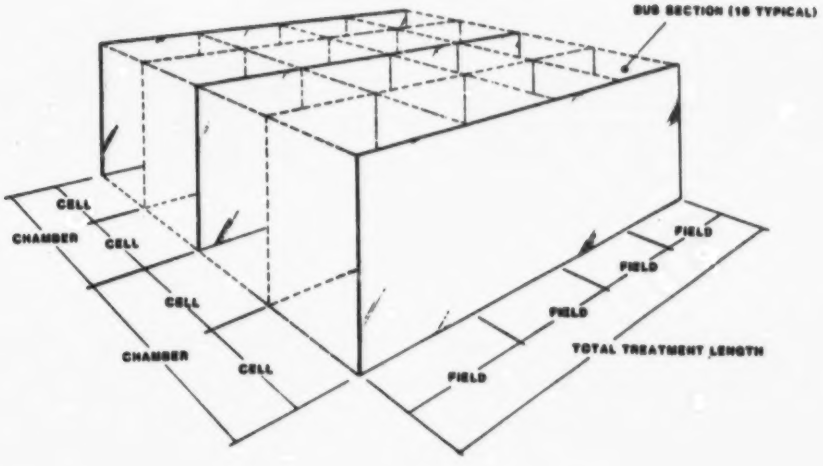
M. Gas Passage

Formed by two adjacent rows of collecting surfaces; measured from collecting surface centerline to collecting surface centerline.

N. Hopper Capacity

Total volumetric capacity of hoppers measured from a plane 10" below high voltage system or plates, whichever is lower.


HIGH VOLTAGE SUPPORT INSULATOR
H.V. BUS DUCT
DISCHARGE ELECTRODE RAPPER
(SIDE LOCATION AVAILABLE)
TRANSFORMER / RECTIFIER
ROOF DOOR
GAS PASSAGE
WEATHER ENCLOSURE
SIDEWALL
SIDEWALL DOOR
COLLECTING SURFACE
INLET NOZZLE
COLLECTING SURFACE RAPPER
GAS DISTRIBUTION DEVICE
DISCHARGE ELECTRODE
HIGH VOLTAGE SUPPORT FRAME
SLIDE BEARING


BUS SECTION (16 TYPICAL)
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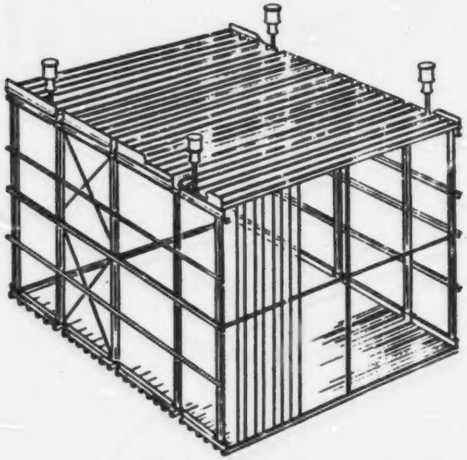
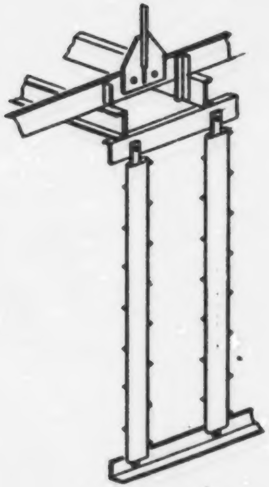
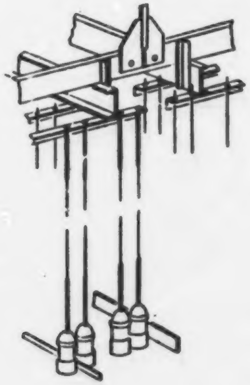
TYPICAL ELECTRODES



RIGID FRAME



RIGID DISCHARGE ELECTRODE (RDE)



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